APPLICATION OF HOLOGRAPHIC INTERFEROMETRY TO THE EXTERIOR BALLISTIC FLOW FIELD IN THE MUZZLE ENVIRONMENT OF A TWENTY MILLIMETER CANNON

Robert Gene Bettinger

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THESIS

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by

Robert Gene Bettinger

June 1975

Thesis Advisor Daniel J. Collins

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Application of Holographic Interferometry to the Exterior Ballistic Flow Field in the Muzzle Environment of a Twenty Millimeter Cannon

by

Robert Gene Bettinger
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LIST OF SYMBOLS

Symbol	Definition
A	cross-section area
C_o	constant specifying thickness of shock region
d	projectile nose diameter
E	specific internal energy
j	mass point number
M	mass
n	cycle number
p	pressure
q	artificial viscosity
t	time
u	velocity
V	specific volume
x	Eulerian position
ΔS	shock standoff distance
ρ	density

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I. INTRODUCTION

A thorough knowledge of the physical characteristics of the internal gas flow field is essential in ballistic design. The flow field that is created and exists ahead of the projectile external to the barrel of any ballistic device also plays an important role in the performance of the projectile. The projectile must traverse this unsteady flow field prior to entering a freestream environment and may therefore have its trajectory altered by this field. Projectile design then may be highly dependent on an understanding of the properties of this flow field existing at the muzzle face. Design of muzzle devices intended to control this environment must also stem directly from knowledge of these characteristics.

A number of experimental and theoretical studies of this external field have been conducted and have shown it to be a complicated structure of mixed supersonic and subsonic flow with a network of shock and expansion areas.

Oertel [Ref. 1] has examined the development of the field using a muzzle flow simulator and a multiple pulse laser to produce a sequence of laser interferograms. The luminosity of this field has been studied by Schröder and Klingenberg [Ref. 2] using small caliber guns of low muzzle velocities with spectroscopic techniques. Theoretical studies have included the development of a numerical scheme which simulates

the blast field and introduces the projectile into the field to determine the effects of the field on the projectile [Ref. 3].

Holographic interferometry has been successfully applied in the study of a wide range of aerodynamic flow problems because of its capability of allowing the investigator to store transient wavefront information for later recall. This aspect of the technique is particularly appealing to the inherently short duration ballistic flow fields. Recent advances in the area of fringe data reduction have greatly reduced the time and energy involved in obtaining density distributions from the interferometric data.

This investigation was conducted in three separate segments:

1. Application of the holographic interferometry technique to the study of the gas core characteristics in the muzzle environment of a 20-millimeter cannon.
2. Experimental measurement of the gas core temperatures and pressures at the breech of the cannon using high frequency pressure transducers and thermocouples, and muzzle velocity measurements taken with a precision chronograph triggered by projectile passage through optical velocity screens.
3. Analytical prediction of muzzle velocities and pressure histories using standard inviscid theory.

II. HOLOGRAPHIC INTERFEROMETRY

The utility of holography as an interferometric tool was recognized in the mid-1960's, shortly after the introduction of the laser as a coherent light source for wavefront reconstruction. Interferometry is the technique of combining two beams of coherent light, that is, beams with a well-defined and non-varying phase relationship. The resulting light and dark interference bands or fringe pattern may be used to measure displacements, density variations and wave characteristics. The use of holography greatly enhances the interferometric technique. The unique property of holography is that it permits photographic storage of a transitory wavefront, which is then available for later reconstruction at the convenience of the investigator. This property then permits interferometric comparison of beams of short duration or beams not simultaneously available.

Two techniques of holographic interferometry are of particular importance. The first of these is called "real time" interferometry. Figure 1 provides an illustration of this technique. In this process, a hologram is first produced of the subject in its unperturbed state. After processing, the photographic plate containing the hologram is replaced in its exact exposure location relative to the original subject and all optical equipment. The subject is then placed in its perturbed state. The hologram and subject are then re-illuminated with the

original subject and reference wavefronts. The original undisturbed subject wavefront is reconstructed and interferes with the perturbed subject wavefront, producing a fringe pattern. Changes in the fringe pattern resulting from varying perturbations may then be continuously monitored.

The second method with numerous applications is the double exposure technique. The hologram is exposed twice prior to processing, with the subject in both the perturbed and unperturbed states. Upon reconstruction, both waves are simultaneously reproduced and interfere, creating the desired fringe pattern. This technique has several advantages over the "real time" technique. More flexibility of observation is attainable and distortion due to emulsion shrinkage is eliminated. Additionally, optical components of lower quality may be used, since the double exposure cancels optical component defects. Unfortunately, the technique permits analysis of only a single distorted state per hologram.

If the optical path between exposures is unchanged, and no disturbance is introduced into the field, the resultant fringe pattern is referred to as the "field of infinite fringe" and consists of a single fringe of infinite width. With the disturbance introduced on the second exposure, small phase shifts in the subject field produced by changes in the optical path length result in a limited number of fringes. If a slight displacement or translation of the scene beam is initiated between exposures, a

framework of sharply defined parallel fringes of selectable spacing is introduced into the hologram. This "finite fringe field" represents lines of constant differences in optical path length. The spacing and clarity of the finite fringe pattern is dependent on the amount of translation or rotation of the scene beam. A quantitative relationship between fringe spacing and rotation or displacement is provided by Floyd & Collins [Ref. 6]. If the subject is then perturbed for the second exposure, density gradients are indicated by fringe shifts often more easily analyzed than the infinite fringe field, particularly for small gradients. Measurement of fringe shifts then allows determination of the density field.

The two most commonly employed schemes for illuminating the object are diffuse lighting and non-diffuse or direct lighting, each of which are illustrated in Figure 2.

Direct illumination is particularly useful for flow visualization of two-dimensional and axi-symmetric flow fields and is generally simpler to set up and use, requiring less intensity for subject illumination. When a diffusing glass is placed in front of the subject, significant changes occur. If the subject is a phase object, each point in the field receives illumination from an infinite number of directions. Thus, each point on the hologram plate receives scattered light from every point in the subject. The entire subject may then be viewed by illuminating any part of the hologram. Different views of the subject are

obtainable by re-illuminating different portions of the hologram plate with the reference beam. Three-dimensional diffusely reflecting objects scatter light in a similar manner as the diffusing glass and thus the glass may be omitted when producing holograms of these subjects. Three-dimensional images of opaque objects may be reconstructed and photographed from different viewing angles using a single hologram.

Diffusely illuminated subjects produce holograms with light field backgrounds which are easier to view than the dark background of direct illumination. A problem arising with diffuse lighting is that the loss of spatial coherence between the interfering waves often causes localization of the fringe system in a plane other than that of the subject. If this separation is too large, it may become necessary to use a lens system with a large depth of field to image both the subject and fringes. Such a system may place limits on the resolution obtainable.

A primary consideration in the technique of holographic interferometry of flow fields is the source of coherent light. In order to maintain the stability of the flow field necessary for high resolution holograms, it becomes necessary to shorten exposure times to the point where changes in the optical path length are restricted to less than the wavelength of light.

The Q-switched pulsed ruby laser has proved to be an excellent light source for these applications. It provides the high power

necessary to expose the plate in a time frame suitable for freezing the motion of the flow field. The wavelength of this laser is compatible with certain commercially available holographic film plates. An additional advantage of this system is that it provides a coherence length of approximately 1 meter, thus eliminating the need to precisely match the path lengths of the reference and scene beams. The short pulse length of this laser makes it mandatory to provide a secondary continuous wave laser beam coincident with the ruby beam for alignment of the optical components. A description of the common technique for placing these beams in coincidence is available in Ref. 7.

III. EXPERIMENTAL LAYOUT

A. GENERAL PHYSICAL ARRANGEMENT

The 20-mm cannon was mounted muzzle end facing outward on a steel rocket test stand within a test cell at the Naval Postgraduate School Rocket Laboratory. These test cells measured 12' x 17' with reinforced concrete walls 12 inches thick. The barrel was secured horizontally to the test stand via two steel mounts at a height of $6\frac{1}{2}$ inches from the stand to the barrel centerline. Two large wooden tables were constructed the length of the test stand and placed parallel to it, one on each side for housing the optical system. These tables were rigidly fastened together and isolated from the test stand to maintain stability and minimize vibrational effects from the cannon blast. Plywood covers were constructed for the tables to protect the optical components and provide the necessary light shield for the holography. The tops to these plywood covers were hinged to allow easy access to the optical components. The general layout of the cell can be seen in Figure 3.

The electrical firing mechanism for the cannon was placed on the test stand at the breech end. All controls for firing the cannon were located remotely in a control room directly behind the back wall of the test cell. The projectile was fired into a bullet trap located 13 feet outside the cell. The trap was designed for the bullet to first impact

on an 18" x 18" x 1½" armor plate tilted 45° from the path of the projectile. This first contact shattered the shell and deflected the fragments into a steel-encased sand trap measuring 5' x 5' x 2½'. The sand trap itself was again shrouded with sand bags for additional safety. The entire trap was housed in a steel turret for a 5" gun mount measuring approximately 15' x 20' x 10'. Figure 4 shows the front of the turret and projectile path.

The ruby laser and all of its components were placed in the test cell adjacent to the cannon. This was done partly for space considerations and also for protection of the ruby laser components. The rail containing the laser cavity was mounted on a specially constructed table and faced normal to the wall separating the cells. A 2-inch hole was drilled through the concrete wall to allow beam passage. The cell was provided with a water source for the laser head and output etalon cooling system. The laser was equipped with a remote control unit so that it could be fired either from the test cell or the remote control room.

B. OPTICAL SYSTEM

The holographic optical schematic is shown in Figure 5. The laser system used for the actual holography was the Korad K-1 pulsed ruby laser. This system is capable of delivering high power, single transverse mode output in the Q-switched mode of operation. A Pockels cell was used to provide the Q-spoiling necessary for peak

power output. When operated in the TEM_{oo} mode, typical values for pulse energy and pulse width are 0.050 joules over 20 nanoseconds, yielding a peak power of 2.5 megawatts. The output beam is approximately 2 mm in diameter with a wavelength of 6943 Å and a coherence length in excess of one meter. The laser head was equipped with a high optical quality holographic ruby rod. Figure 6 provides a photographic view of the laser installation.

After first passing through the holes in the wall and plywood cover, the beam then passed a narrow-band filter which served to remove the undesired light from the Xenon flash tube. After next passing a series of neutral density filters used to control intensity, the beam then contacted a 2-inch round beam splitter which divided it into two wavefronts of approximately equal intensities. The subject beam was reflected down the centerline of a 2.5 meter optical bench through a series of expanding, collimating lenses to mirror #1. These lenses were designed to expand the subject beam to a size compatible with the field of interest and the 4" x 5" hologram plate. Mirror #1 was secured to a precision gimbal mount which allowed rotation about both the vertical and horizontal axes. This mount provided the precise beam rotation necessary to produce the finite frinte field for interferometry. Mirror #1 directed the beam through the test section and a dual grid system in a direction normal to the axis of the cannon.

The beam was then reflected from mirror #2, which directed it along a 1.5 meter optical bench through a set of imaging lenses with

a focal length of 22 inches. The purpose of this set of lenses was to image the test section closer to the hologram plate providing a sharper image with greater fringe contrast. This set of lenses converged the beam to a point at which a second narrow-band filter was placed to remove the flash from the muzzle blast. The beam then passed to mirror #3 which directed it to the hologram plate.

After passing the beam splitter, the reference beam contacted mirror #4 on a 2.0 meter optical bench which allowed adjustment of the reference beam path length to that of the subject beam. From mirror #5 the beam was directed to the hologram plate through two series of expanding-collimating lenses which enlarged the beam to approximately a 4" diameter at the plate. All mirrors in the system were provided with screw type adjustments for vernier-scale movement about their horizontal and vertical axes, thereby greatly simplifying alignment procedures.

The optical benches were bolted to the tables on specially designed crossfeet which allowed the benches to be leveled with two knob adjustments provided on each crossfoot.

For alignment the system was equipped with a Coherent Radiation 3 milliwatt helium-neon continuous wave laser. This laser was mounted on a stand perpendicular to the axis of the ruby laser cavity. By placing a mirror at a 45^{o} angle in the ruby laser cavity, this CW beam could be placed in coincidence with the ruby laser beam.

The overall performance of the optical system was measured through the use of the USAF 1951 resolution test target (Figure 26). The target was placed in the test section and a hologram taken. Examination of the reconstruction of this hologram (Figure 27) reveals a minimum resolution of 3.5 lines per mm which is more than adequate for the fringe shift measurements necessary in the conduct of the interferometry. Figure 7 is a photographic view of the optical arrangement.

C. BARREL INSTRUMENTATION

For measurement of the pressure-time history at the breech end, the barrel was equipped with Kistler 607A pressure transducer installed 5½ inches from the breech end of the barrel. This location was just ahead of the tip of the projectile prior to firing. The signal from the transducer was passed to a Kistler Model 504 Universal Charge Amplifier in the control room and then displayed on a Textronix storage oscilloscope.

Gas core temperature measurements were made at the breech with a special Nanmac tungsten-rhenium thermocouple mounted directly opposite the Kistler transducer. The output from this thermocouple was displayed on a Hewlett-Packard OS 209 (P) oscilloscope.

For muzzle velocity measurements, the projectile was fired through two Oehler Model 55 Ballistic Velocity Screens placed in the path between the muzzle and the sand trap. These screens can be seen in Figure 4. As the bullet passed through each screen, a 12-volt pulse

with an adjustable 2-8 millisecond pulse length was produced and sent to an Oehler Model 21 Chronograph. These pulses provide start and stop signals for the chronograph. This provides a time of passage between the two screens. The screens are placed a known distance apart and thus an average velocity between the two can be calculated. These velocities are tabled for various screen separations. It was found that the first screen had to be placed at least 4 feet from the muzzle to prevent the blast from pre-triggering the screen prior to projectile passage. Figure 8 is a photograph of the control room instrumentation including the fire control panel.

IV. FIRING SEQUENCE

After optical system alignment and warm-up of all electrical components, the test cell was closed and a hologram plate installed in its holder. The laser was fired from its direct control for the first plate exposure of the unperturbed field. This first exposure creates the hologram of the static test section which will later be used to interfere with the second hologram of the flow field. For the finite fringe holograms, mirror #1 was then rotated to produce the desired fringe field for the reconstruction process. Mirror #1 mount was equipped with two micrometer adjustments which provided 20 arc seconds of beam rotation for each unit of micrometer movement. Beam rotation of approximately 100 arc seconds between shots provided the fringe field desired. For infinite fringe holograms mirror #1 was not moved.

After producing the reference hologram the cannon was loaded. The individual who was loading the cannon and connecting the firing mechanism carried with him a safety key which breaks the firing circuit at the control panel to prevent accidental firing prior to his clearing the test area. The laser was then charged remotely from the control room and a horn was sounded to provide final warning of the impending shot. The firing sequence was then initiated. A schematic of this sequence is shown in Figure 9.

While the laser capacitor bank was charging, the safety key was installed in the fire control panel and power supplied to the firing mechanism. When the laser was ready, the firing mechanism capacitors were charged and the cannon then fired. The process could be observed through two glass viewing windows connecting the control room and the test cell.

To provide accurate timing for firing the laser coincident with projectile passage through the test area, it was necessary to use the pulse from the Kistler transducer to initiate the laser firing sequence. After a number of measurements, it was found that for the studies outside the barrel, projectile passage through the test area occurred at approximately 1600 microseconds after the triggering of the Kistler. The laser system has an inherent delay of about 1020 microseconds between discharge of the capacitor bank and lasing action with Pockels cell Q-switching. Additionally, the output voltage from the Kistler charge amplifier was not sufficient for triggering the laser. It was therefore necessary to delay and increase the voltage of the Kistler pulse to provide an accurate reliable trigger for the laser system. To do this, the Kistler pulse was displayed on a Textronix storage oscilloscope and simultaneously used as an input to a Hewlett-Packard USM-310(V) signal modulator. This unit permits the input of a variable signal delay which was changed periodically to adjust to point of exposure on the projectile. The delayed Kistler output was routed through an

ILC PG-10 pulse generator which provided the voltage necessary to trigger the laser.

Additionally, two electronic timers, a Monsanto Model 101 B and a Dynasciences CP-929 were integrated into the system at various locations to provide checks on intervals of interest. These are shown in typical locations in the firing sequence schematic.

After firing, the test cell was closed and the hologram plate removed for processing. The armor plate was checked for damage and repositioned when necessary. The cannon was unloaded and the barrel was periodically cleaned with a standard 20-mm bore brush. The pressure and temperature traces were photographed with a Polaroid C-5 oscilloscope camera.

V. HOLOGRAPHIC FILM AND PROCESSING TECHNIQUE

The wavelength of the coherent light source used in the holography is 6943 Å. It was desirable to use a photographic emulsion with narrow-band sensitivity centered in this region of the spectrum to minimize the effect of extraneous light leakage into the system. The most suitable commercially available emulsion for this purpose was found to be Agfa-Gevaert 10E75 holographic plates. This film has a resolution capability of 2800 lines per mm which is approximately the maximum required film resolution for transmission holograms produced with 6943 Å light. A spectral sensitivity curve for this emulsion may be found in Ref. 4.

Processing of the exposed hologram plates consisted of a five-minute bath in Kodak D-19 Developer followed by five minutes in a standard fixer. The plate was then washed for five minutes in flowing water and then allowed to air dry prior to reconstruction.

It was not possible to control time of exposure for these plates while using the 20-nanosecond ruby pulse. Therefore, exposure was controlled by using a suitable combination of neutral density filters in the beam to produce the intensity desired at the hologram plate.

For the double pulsed holograms a problem was encountered due to the fact that the projectile was not in the field for both exposures as is normally the case when utilizing this technique to observe flow

fields around opaque objects. For single exposure holograms the bullet appears as a dark object in a light background, while for double exposure holograms the bullet was a light object on a light background. This lack of contrast was improved appreciably by halving the intensity of the first exposure. This provided a grey background for the bullet upon reconstruction, while yielding good fringe contrast.

VI. RECONSTRUCTION

In reconstruction of the holograms, two different techniques were employed using different sources of coherent light for the reconstructing reference wave. For the first of these, illustrated in Figure 10, a 15-milliwatt Spectra-Physics continuous wave, helium-neon laser was used for the reconstructing wave. This laser was equipped with an integral lens system which produced a 50-millimeter collimated beam. This beam was expanded and collimated with a secondary set of lenses to the approximate size of the hologram plate. The converging real image was then photographed with a single lens reflex 35-millimeter camera, using Kodak Panatomic-X (ASA 32) fine grain black and white film.

The second reconstructing procedure used is illustrated in Figure 11. A one-watt continuous wave argon laser was employed to reconstruct overexposed holograms requiring a more intense reference beam. To minimize the possibility of accidentally viewing the powerful reference beam during photography, the reconstructed scene beam was reflected away from the reference beam with a high quality first surface mirror. As suggested by Trolinger [Ref. 11], the actual imaging lens used in the construction of the hologram was placed in the reconstructed scene beam to eliminate spherical aberrations produced by this lens during construction. This lens then served to recollimate the scene

beam. In practice, little or no improvement was observed in the quality of the reconstructed beam. Thus this lens was not used in the first technique.

The real image was again photographed with the single lens reflex camera and Kodak film.

VII. COMPUTER PROGRAM FOR PREDICTION OF FLOW PARAMETERS

The computer program used for the prediction of the muzzle velocity and pressure history of the flow field was an adaptation of a program developed at the Naval Ordnance Laboratory to analyze the performance of hypervelocity model launchers [Ref. 8]. The analysis was essentially a one-dimensional, Lagrangian scheme in which the field was divided into six regions, each of which then was subdivided into zones. Each region had specified its own equation of state which, depending upon the material characteristics of the region, could be either solid, ideal, or non-ideal gas equations. At the interface of each zone were inserted mass points, each of which was assumed to consist of one-half of the mass of the adjacent zone. The analysis successively applied the hydrodynamic equations in finite difference form to each mass point over the time interval of interest. The method employed was the "q" method of Von-Neuman and Richtmyer [Refs. 9 and 13].

The equations applicable to the scheme were the following:

Isentropic Flow energy equation:

$$\frac{\partial E}{\partial t} = -(p + q) \frac{\partial V}{\partial t}$$

Equation of motion:

$$\frac{\partial u}{\partial t} = -\frac{\partial (p + q)}{\partial x} \frac{1}{M} A(x)$$

Equation of state:

$$p = p\ (E, V)$$

with

$$M = \int^{x} \rho\ (x)\quad A(x)\ dX$$

$$q = \begin{cases} \dfrac{C_o^{\,2}}{V}\ \left(\dfrac{\partial u}{\partial j}\right), & \dfrac{\partial u}{\partial j} < 0 \\ 0, & \dfrac{\partial u}{\partial j} \geq 0 \end{cases}$$

The artificial viscosity term "q," which was added to the pressure term in the energy and motion equations, essentially spreads variable changes created by the shock over a finite region. This facilitates computation by allowing the equation variables to be continuous across the shock. The constant C_o permits adjustment of this shock "thickness."

For computation purposes these equations were written in finite difference form. Initial values of E_o, p_o, and V_o are provided for each region. Stability was maintained during the process by recalculating a new time increment for every cycle in the process.

During each cycle, the pressure at each mass point was calculated using the equations of state and energy. From the pressure differential at these interfaces the acceleration and velocity of each mass point were obtained using the equation of motion.

Required data inputs included initial temperatures, pressures, and molecular weights for each region, along with a series of variables

describing the geometry of each region. Additional inputs describing burning characteristics were required for each region containing powder.

The program was written in FORTRAN and a listing along with the input format is given in Appendix A.

VIII. HOLOGRAPHIC RESULTS

Considerable trial and error was involved in the initial attempts to capture the projectile and its associated flow field at the muzzle of the barrel. The optics of the system were initially designed primarily for investigation of the interior flow behind the projectile and thus the available size of the scene beam was limited. The average view of the test section was circular of 4-cm diameter centered 2.5 cm outside the muzzle. Initially a barrel-mounted dual grid system (one grid on each side of the test section) was installed on the barrel. These grids were removed and replaced with a central vertical wire for viewing orientation when it was discovered that grid movement due to the blast introduced undesirable noise into the system for the double-pulsed holography.

Prediction of the pulsing instant of the Q-switched laser was reliable to within $\pm$ 10 microseconds. The time of projectile passage through the test section after triggering the transducer varied by as much as 50 microseconds. This variability was reflected in the range of projectile velocities obtained from the velocity screens and was probably a result of differences in powder charge and projectile weight. Because of this unpredictability and also experimentation with relative beam intensities, many shots were fired before meaningful holographic results were obtained.

Among the first successful holograms were a series of single exposures taken while attempting to refine the timing of the laser pulse to coincide with projectile passage through the test area. Figure 12 is the reconstruction of one of these single exposure holograms containing a shadowgraph of the projectile. As an indication of the size of the projectile, the grid in the photograph is $\frac{1}{2} \times \frac{1}{2}$ centimeter. In this particular hologram, the detached bow shock wave is actually discernible. For easier viewing, the projectile and shock are redrawn in Figure 13.

The standoff distance of the shock at the nose of the projectile was 2.7 mm. The approximate nose radius of the projectile was 3.8 mm, yielding a standoff distance to nose diameter ratio of .355.

Van Dyke [Ref. 12] provides theoretical values of this ratio for a sphere as a function of Mach number. His values are obtained through an inverse method in which a marching technique is used to integrate numerically the flow equations from the shock to the sphere. Experimental measurements provided excellent agreement with these theoretical results.

A $\Delta s/d$ ratio of .355 indicated that the projectile Mach number was 2.2 in the region of elevated temperature just outside the muzzle. The precursor traveling shock, well ahead of the projectile at this point, is outside the view of this hologram.

The measured muzzle velocity for this particular shot was 3364 feet per second for a freestream Mach number of 3.0.

After resolving as well as possible the problem of timing the laser firing, double pulsed holography was conducted. Figure 14 is a finite fringe hologram of the precursor traveling shock emerging from the barrel ahead of the projectile. This shock was created by rapid expulsion of the gases within the barrel ahead of the projectile. At the point of exposure, this shock was 1.75 cm from the muzzle along the barrel axis and appears nearly spherical with a radius of 2.25 cm. The steep density gradients across the shock are evident by the extremely closely packed fringe pattern visible across the shock.

Figure 15 is another finite fringe hologram with the precursor traveling shock at a distance of 3.2 cm from the muzzle. At this point the shock radius had increased and had weakened appreciably as indicated by the wider spacing of the fringes. This hologram also reveals a second shock of smaller radius behind the first at 2.6 cm from the muzzle. This inner shock could have been a recompression wave due to overexpansion behind the outer shock wave. Further examination of this hologram also revealed the radial development of the Prandtl-Myer expansion fan around the rim of the muzzle face. The precursor shock from Figures 14 and 15 are redrawn together in Figure 16. As seen in this figure the limited size of the field makes fringe analysis difficult.

Figure 17 is a double-pulsed hologram taken with the nose of the projectile 2.4 cm into the field. The grid system is still in place and

its adverse effects are evident. In this figure a marker on the grid indicating the central portion of the test section is evident on the nose of the projectile.

Holograms of the projectile at increasing degrees of penetration of the flow field may be seen in Figures 18 through 21. Each of these holograms is a finite fringe hologram with varying degrees of fringe separation. The boundary layer was visible in Figures 18 and 21 in the sharp fringe shifts at the projectile surface. As the bullet progressed through the field, less of the field around the projectile was visible due to the limited view of the test area.

In Figure 21 nearly 2/3 of the projectile had passed the center of the test section indicated by the vertical reference wire. With approximately one inch of projectile remaining, the field became blurred and the image of the bullet as well as the fringe pattern disappeared. The beginning of this process was also shown clearly in Figure 20. It is probable that the loss of image at this point was due to leakage of the high pressure combustion gases around the projectile. The flow of these gases is turbulent and tends to obscure the field. Additionally, the combustion effluents caused the gases to become opaque and difficult to observe holographically.

IX. COMPARISON OF ANALYTICAL AND EXPERIMENTAL RESULTS

Sample outputs from the computer program are illustrated in Figures 22 and 23. Figure 22 summarizes the major inputs including initial conditions in the approximate program output format. As seen in this figure, the time increment between printout of calculated flow parameters may be selected arbitrarily. The print interval for this particular run was .2 milliseconds. Figure 23 illustrates the output from the final cycle as the projectile leaves the barrel. The mass point, j, for the projectile is 6 and its velocity (muzzle velocity at this point) is 1064 meters per second. The X position is distance from the breech end to the mass point. Using printout from each cycle, the projectile velocity was plotted as a function of X-distance in Figure 24.

The mean experimental projectile velocity measured with the Oehler velocity screens over a series of 53 shots was 1032 meters per second for an average Mach number of 3.03. The velocities ranged from 1020 to 1056 meters per second and had a standard deviation of 10.7 meters per second. The measurement was taken at a distance of 2.68 meters from the muzzle. Assuming a projectile drag coefficient of .28 [Ref. 10], the average muzzle velocity was approximately 1033 meters per second. This measurement was within 3% of the predicted value.

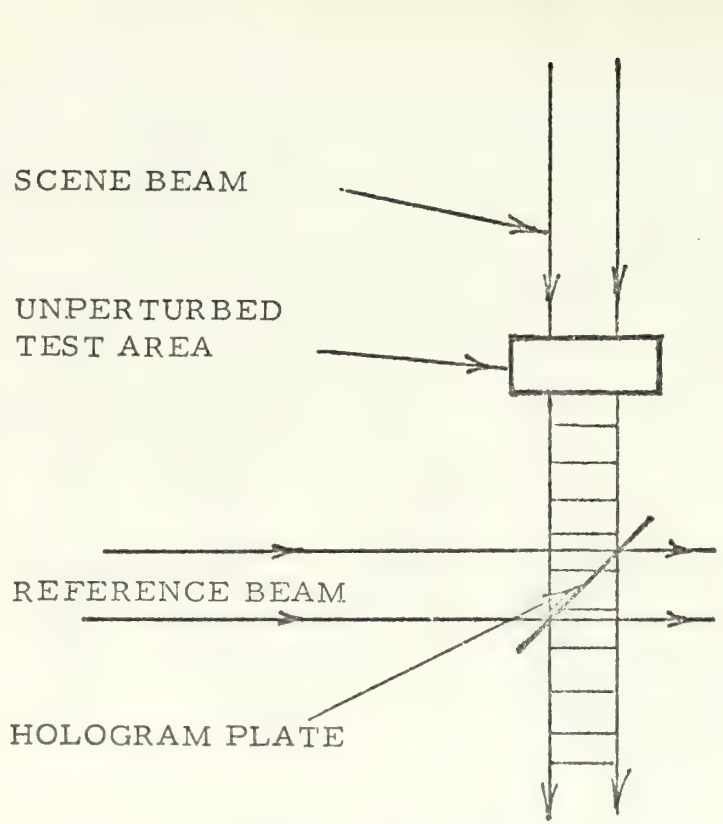
From Figure 23, the computed time of projectile arrival at the test section was 1884 microseconds after the firing pulse. Actual average time of arrival based on holographic evidence of the projectile in the test section was 1600 microseconds after triggering of the Kistler pressure transducer 14.0 centimeters from the breech end. This required a projectile travel of nearly 7 centimeters. From the computer program this estimated time of travel was 378 microseconds for a total of 1978 microseconds. Agreement between predicted and measured values is within 5%.

The computer pressure history at the transducer location was plotted using the zone pressure at the 14-centimeter location for each print cycle. This pressure trace is plotted in Figure 25 along with the actual measurements from the Kistler pressure transducer. Very good agreement was obtained between the actual and numerically obtained pressures. The experimental results show, after an initial overshoot, a peak pressure of 4966 bars at approximately .62 milliseconds after the firing pulse. The predicted pressure history rises and falls somewhat more rapidly than the actual trace, with a peak pressure of 5624 bars at .475 milliseconds after the firing pulse. Excellent agreement is seen between the actual and theoretical pressures after these initial peak values.

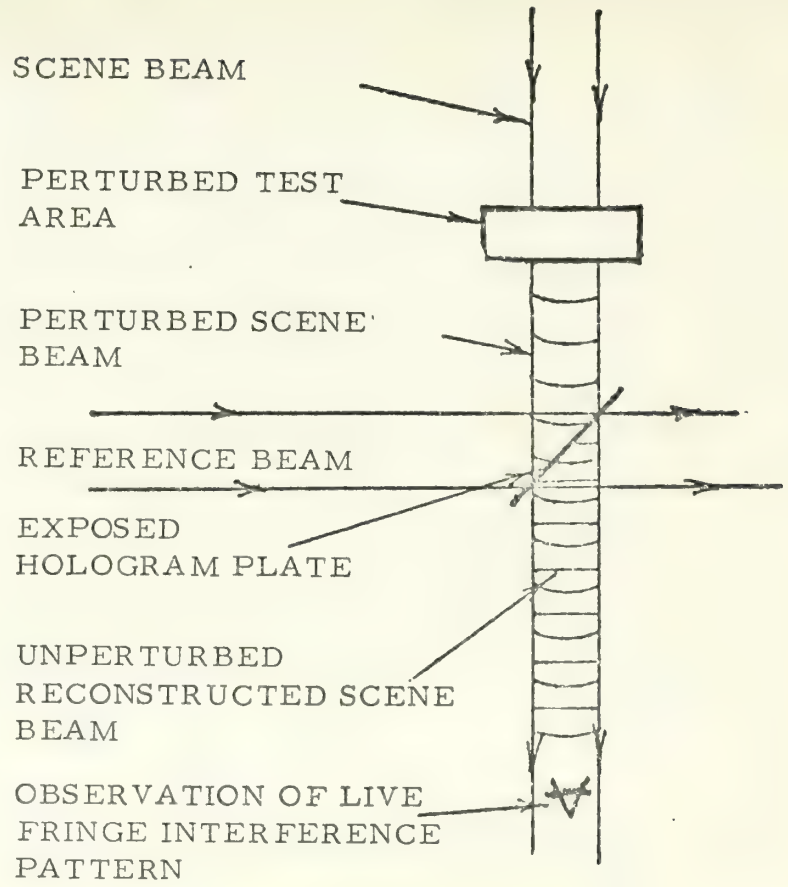
X. SUMMARY AND RECOMMENDATIONS

The numerical solution of the one-dimensional hydrodynamic equations has provided excellent agreement with experimentally measured flow parameters including muzzle velocity, pressure history, and projectile launch time. This program may be used in predicting these parameters under a wide range of initial conditions including variations in powder characteristics, and projectile and launcher size.

The feasibility of the use of holography in the visualization of exterior ballistic flow fields has been demonstrated. Several excellent holograms of the projectile and its associated flow field have been obtained. Interferometric analysis was restricted, however, due to the limited field of view obtained with the present optical arrangement which was initially designed to study interior ballistic flow fields. Currently, the optical arrangement is being modified to provide this enlarged field of view necessary for the interferometry. Additionally it is felt that imposition of a horizontal fringe field rather than the vertical field used in this study would be easier to analyze interferometrically because of the axi-symmetric nature of the flow field. This entails only vertical rather than horizontal rotation of the scene beam between exposures and requires no modification of the current optical arrangement.

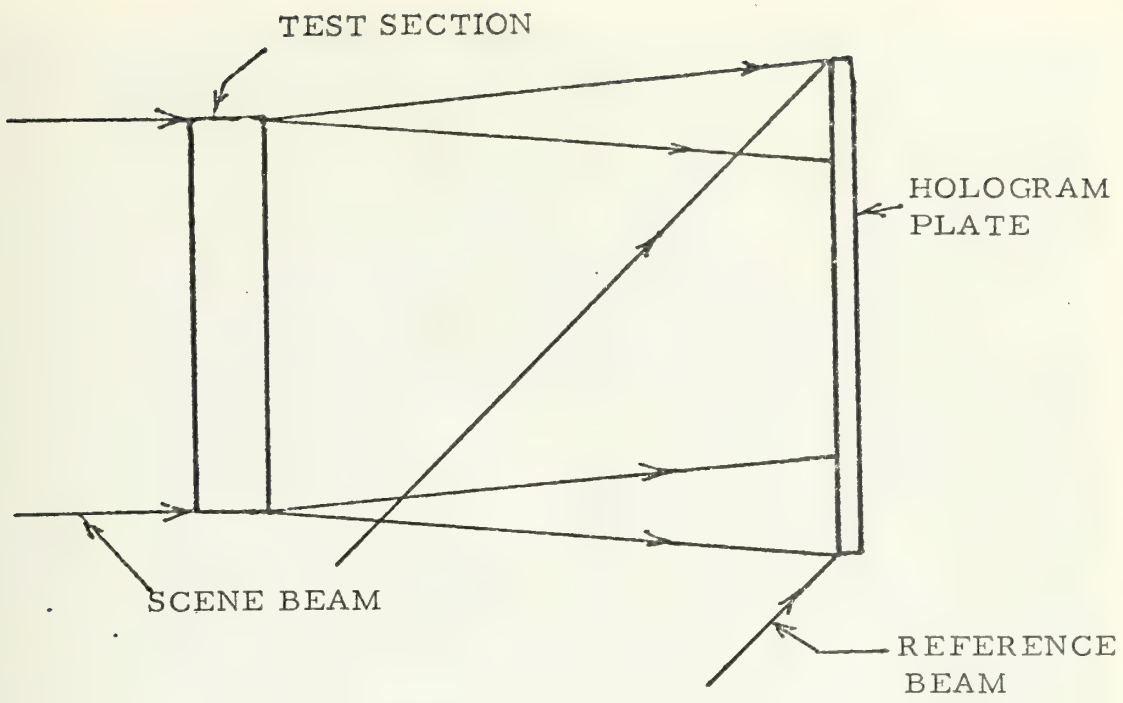


(a) EXPOSURE WITH UNPERTURBED SUBJECT BEAM

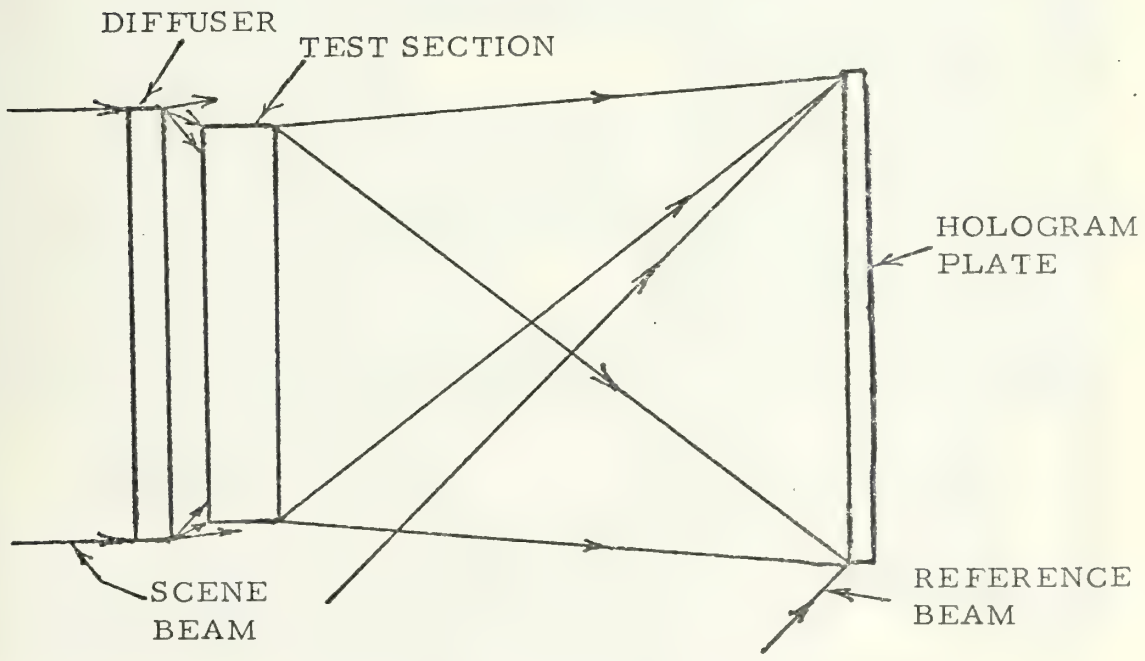


(b) LIVE FRINGE CONSTRUCTION

FIGURE 1.



(a) DIRECT ILLUMINATION



(b) DIFFUSE ILLUMINATION

FIGURE 2.

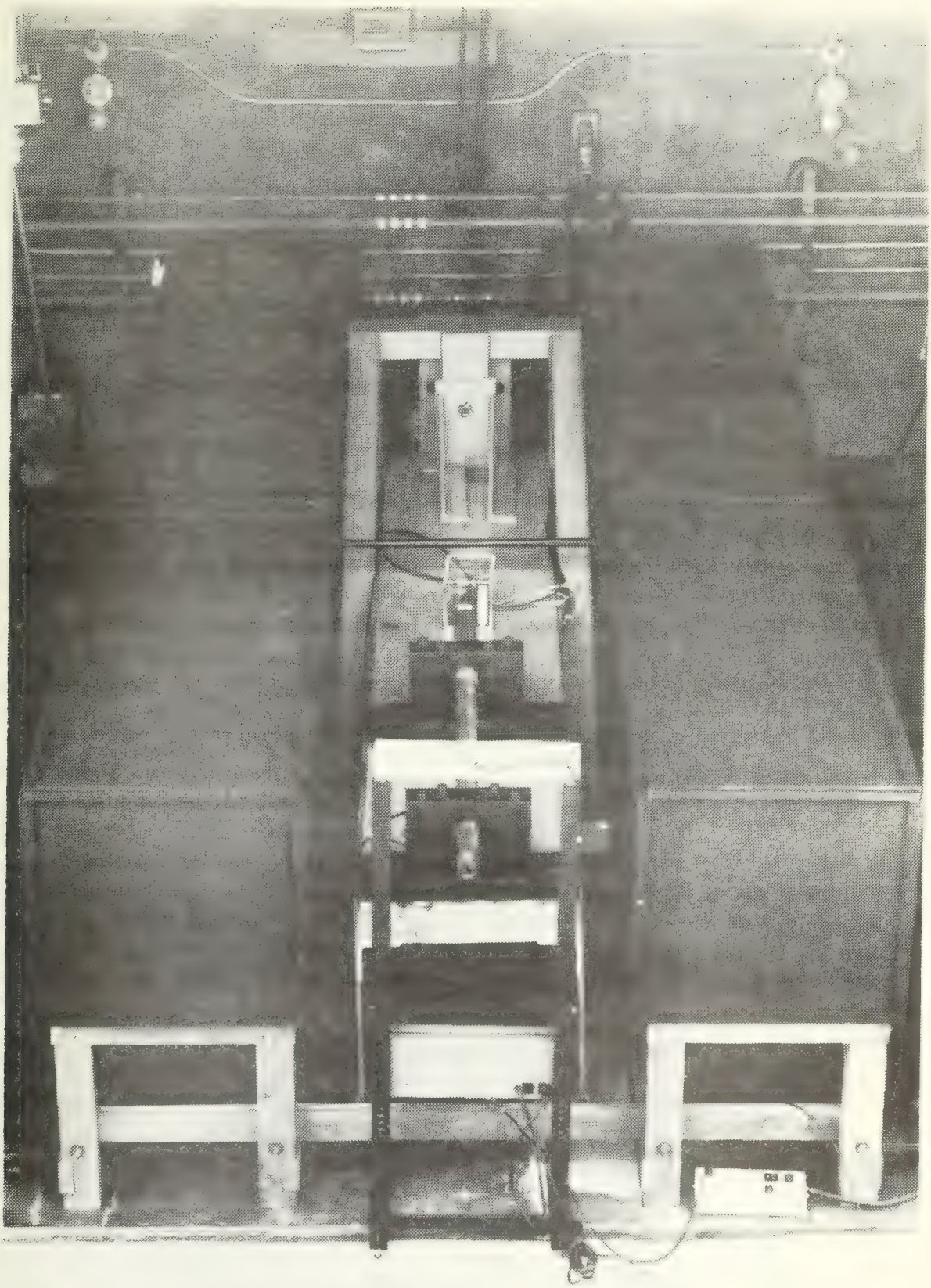


FIGURE 3. TEST CELL LAYOUT

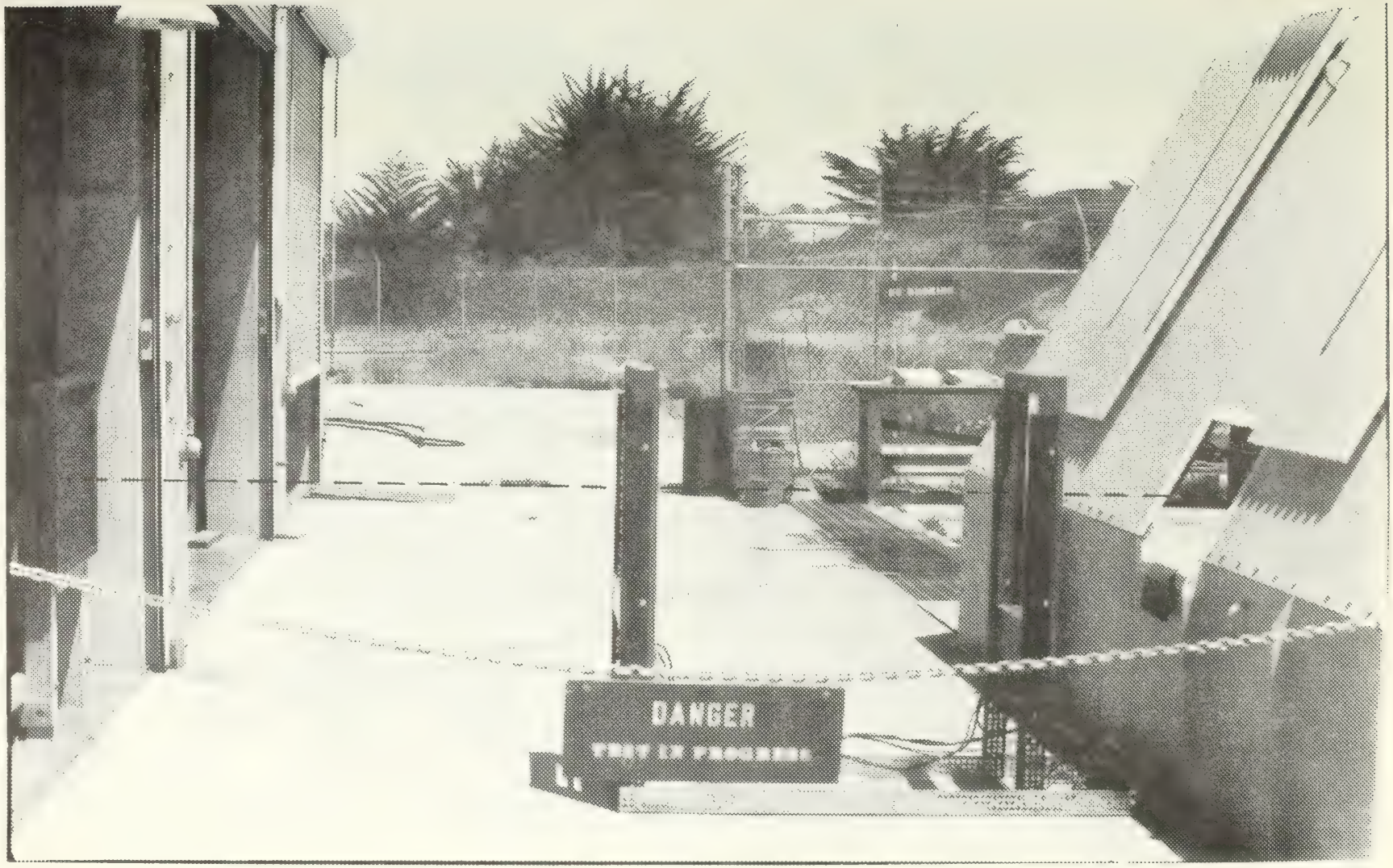


FIGURE 4. PROJECTILE PATH AND TURRET

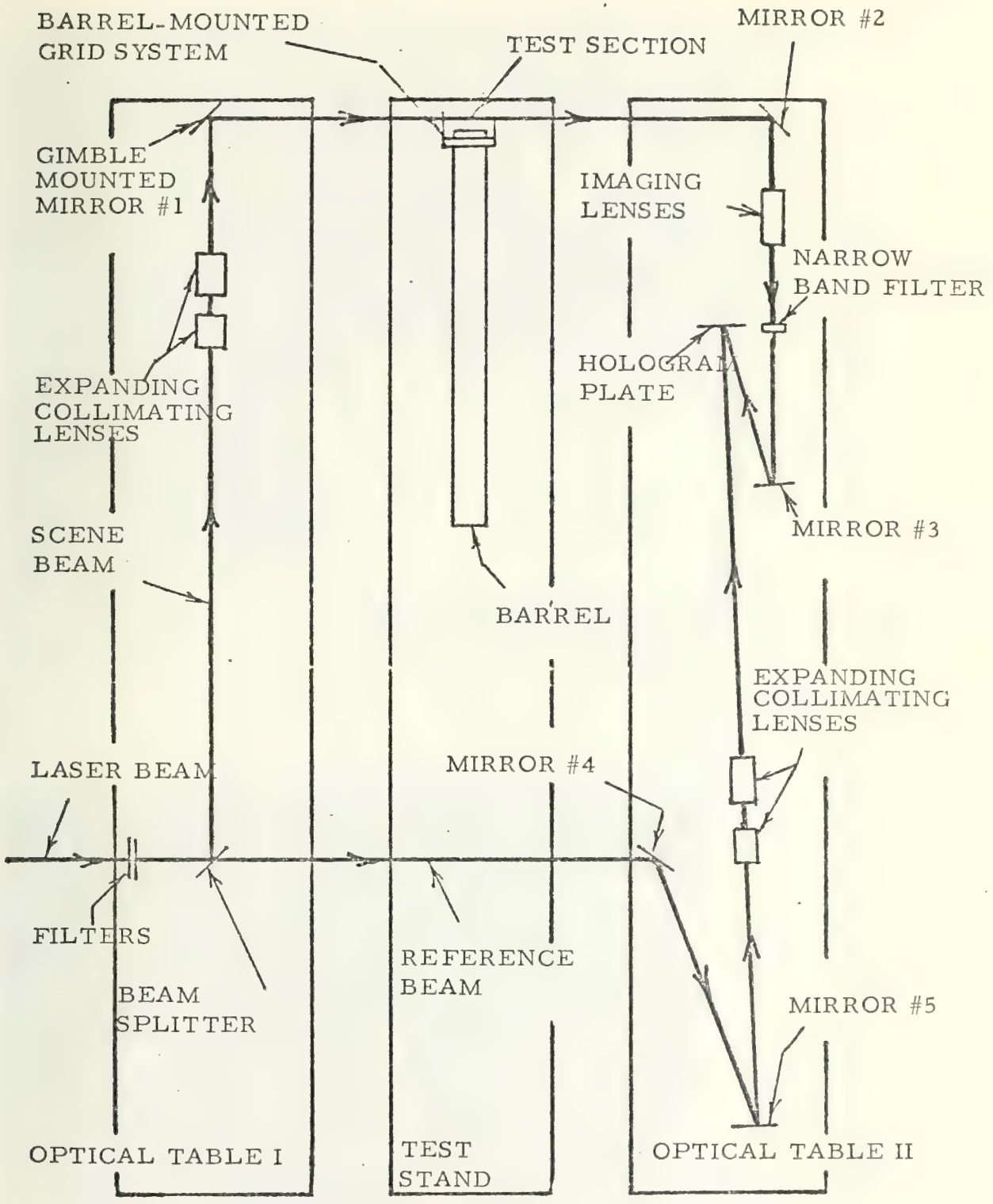
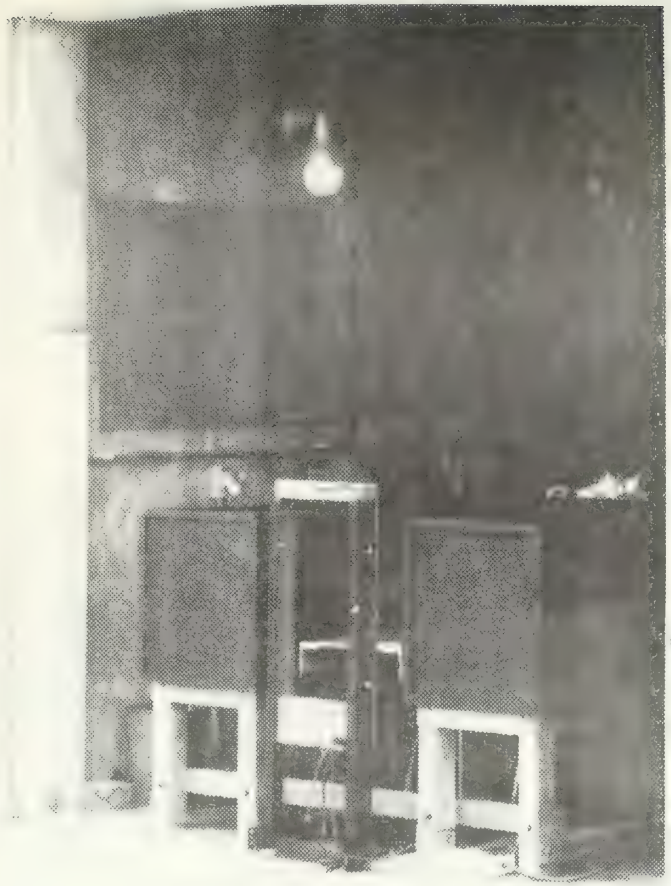


FIGURE 5. OPTICAL ARRANGEMENT



(b) CANNON AND OPTICS TEST CELL

(b) LASER INSTALLATION

FIGURE 6.

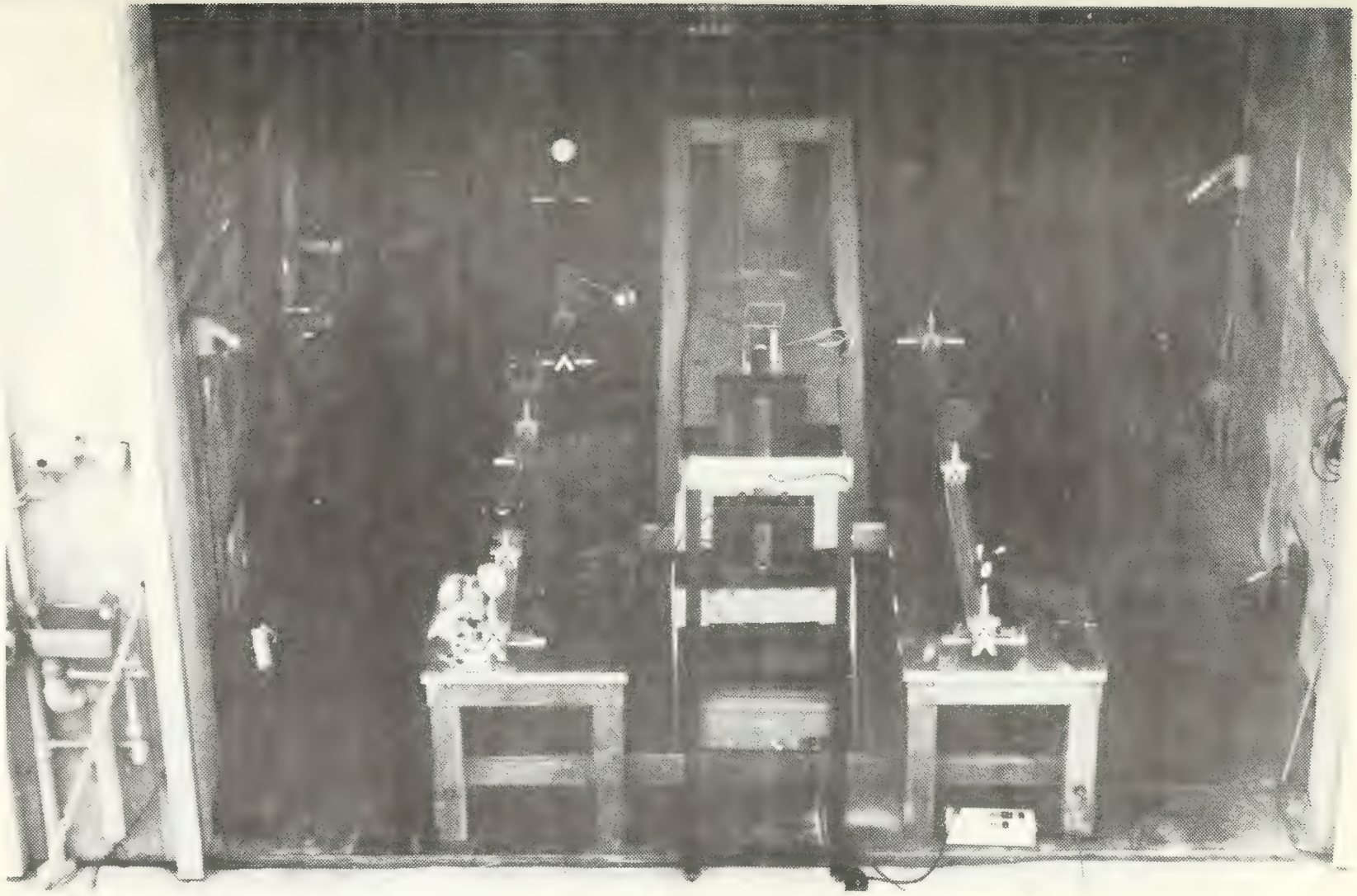


FIGURE 7. OPTICAL ARRANGEMENT

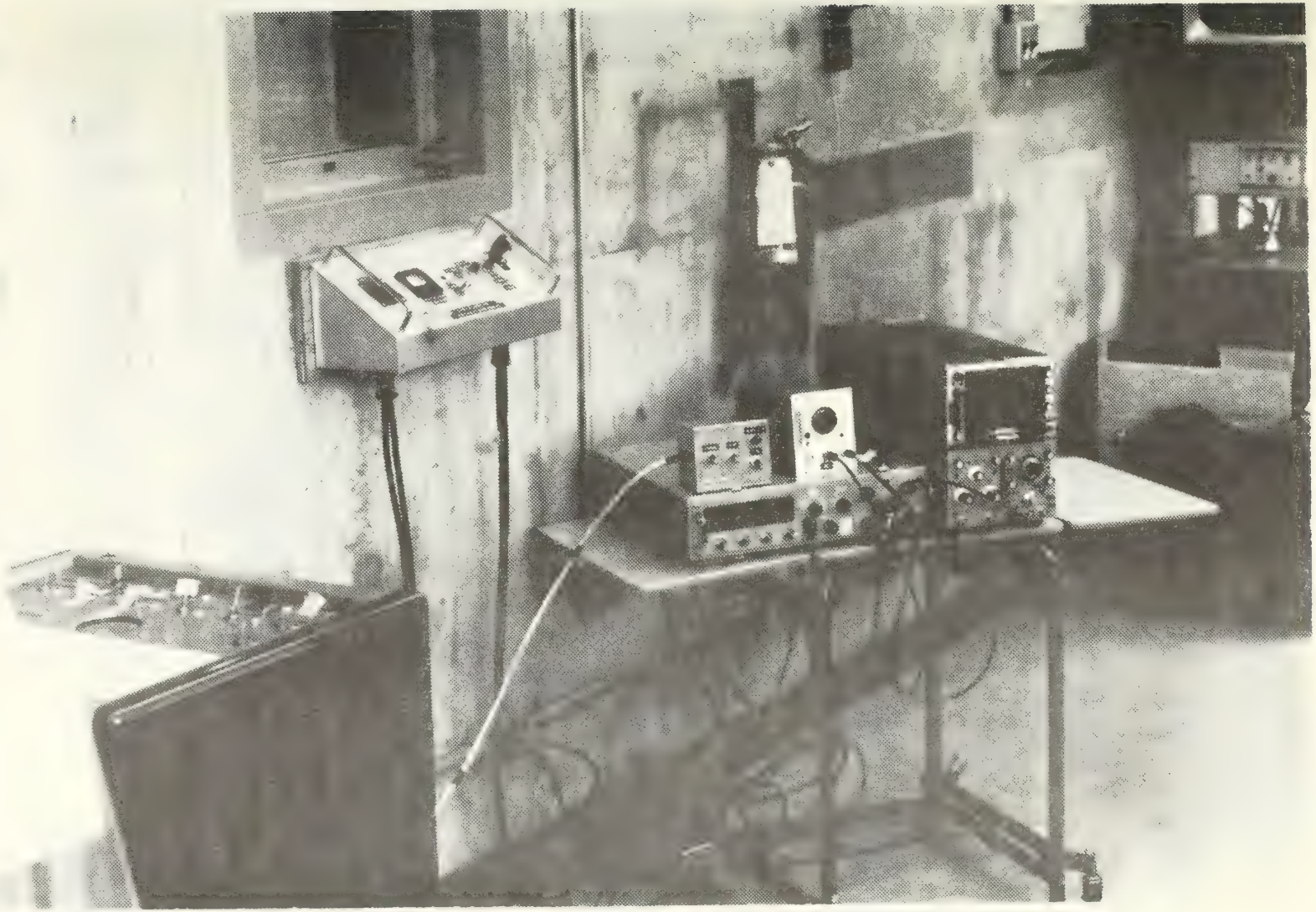


FIGURE 8. CONTROL ROOM INSTRUMENTATION

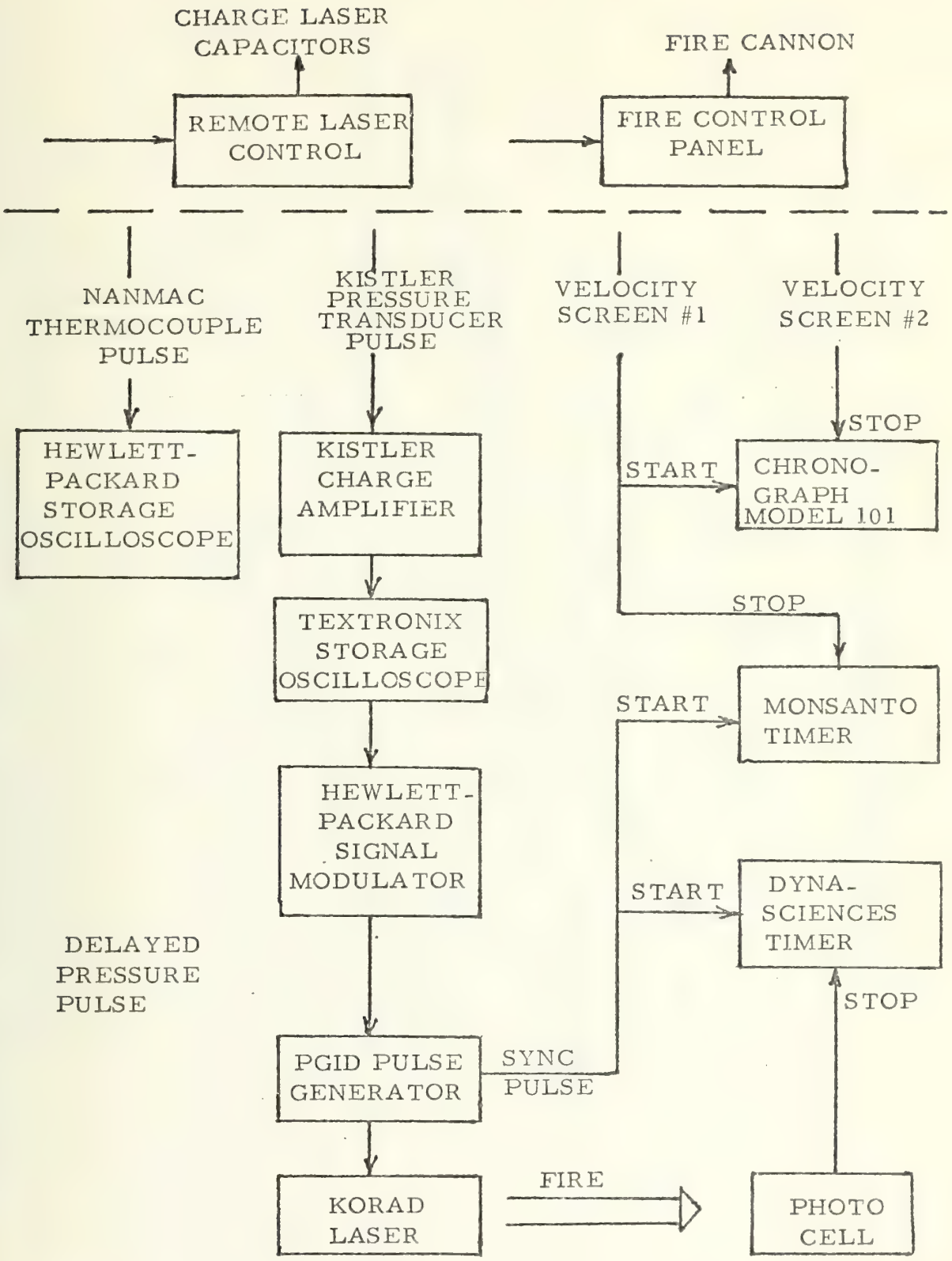


FIGURE 9. FIRING SEQUENCE

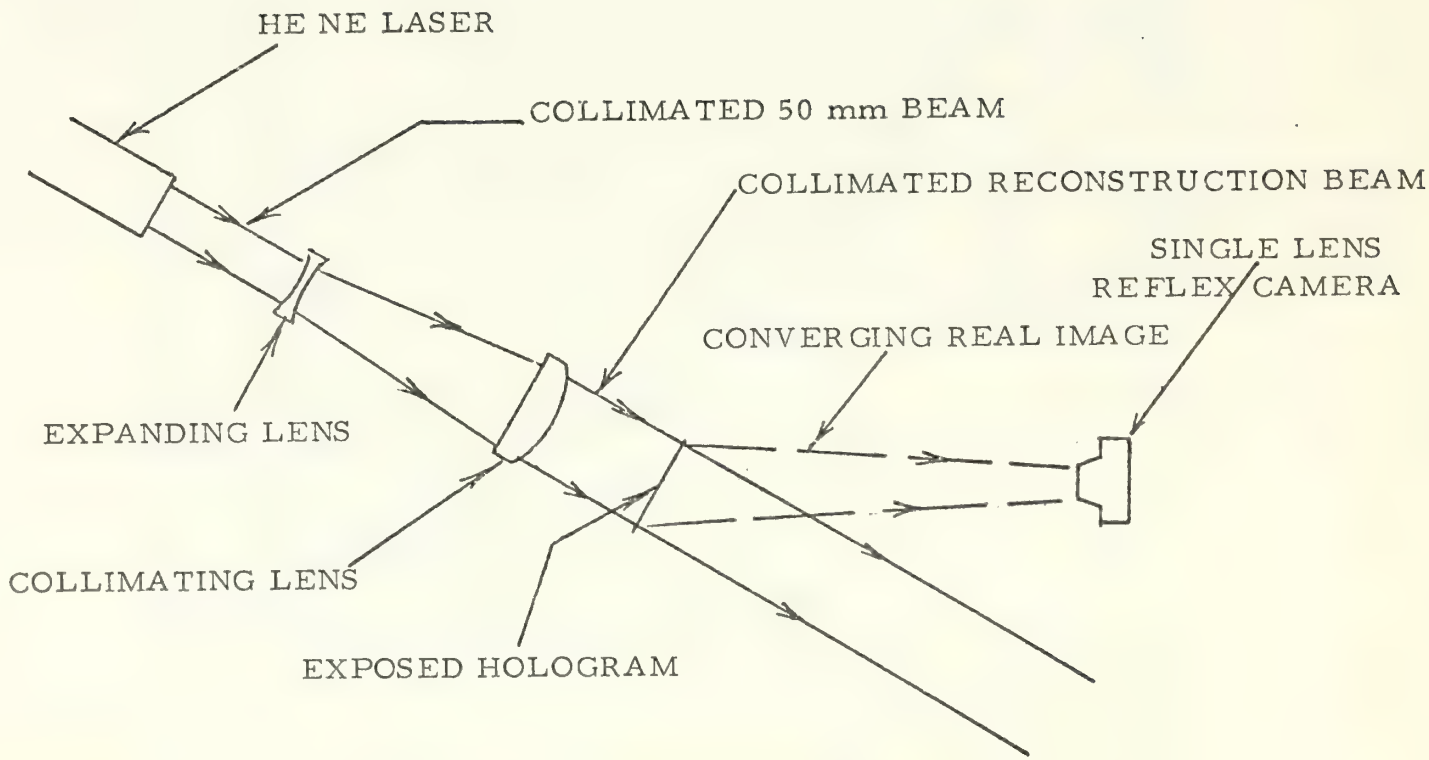


FIGURE 10. RECONSTRUCTION

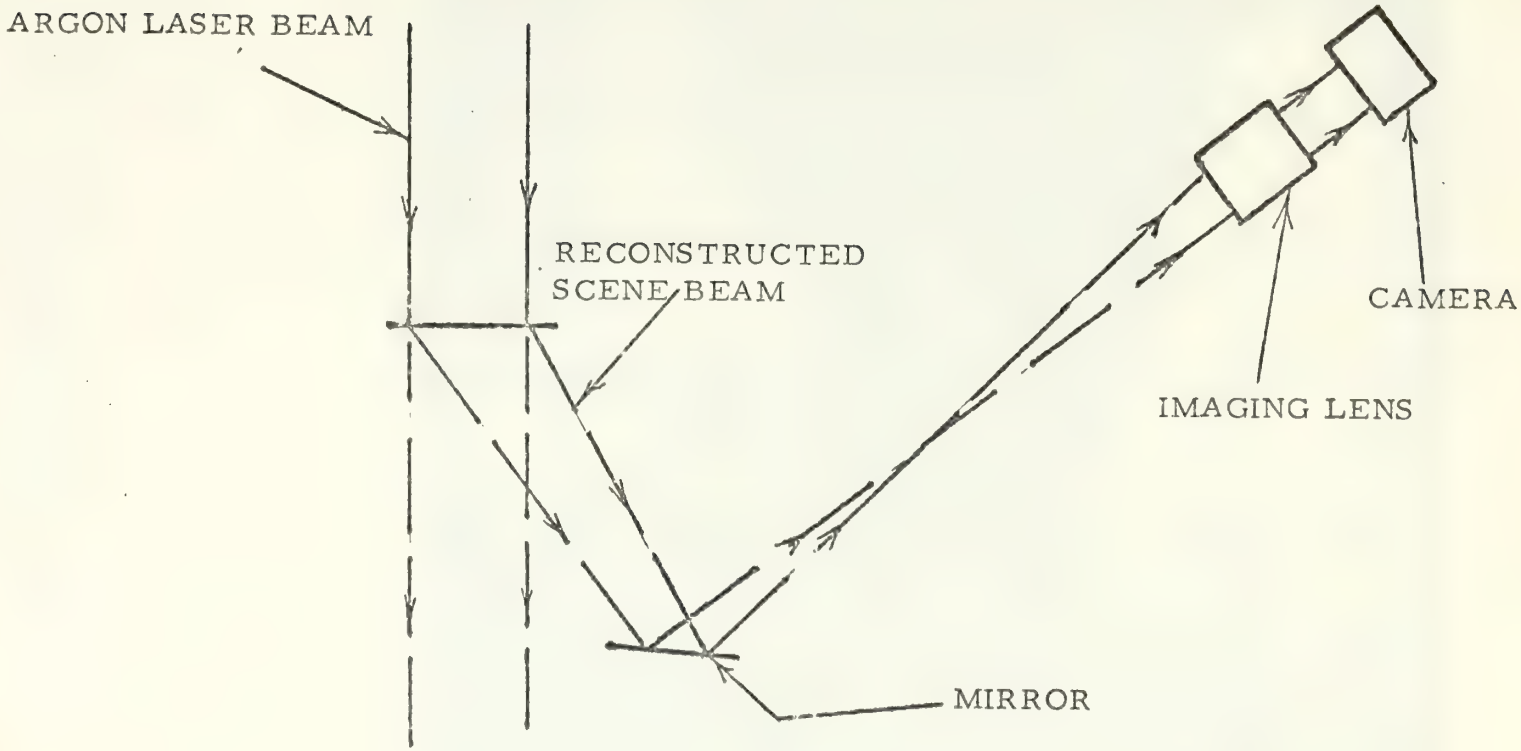


FIGURE 11. RECONSTRUCTION

FIGURE 12. SINGLE EXPOSURE HOLOGRAM
OF PROJECTILE

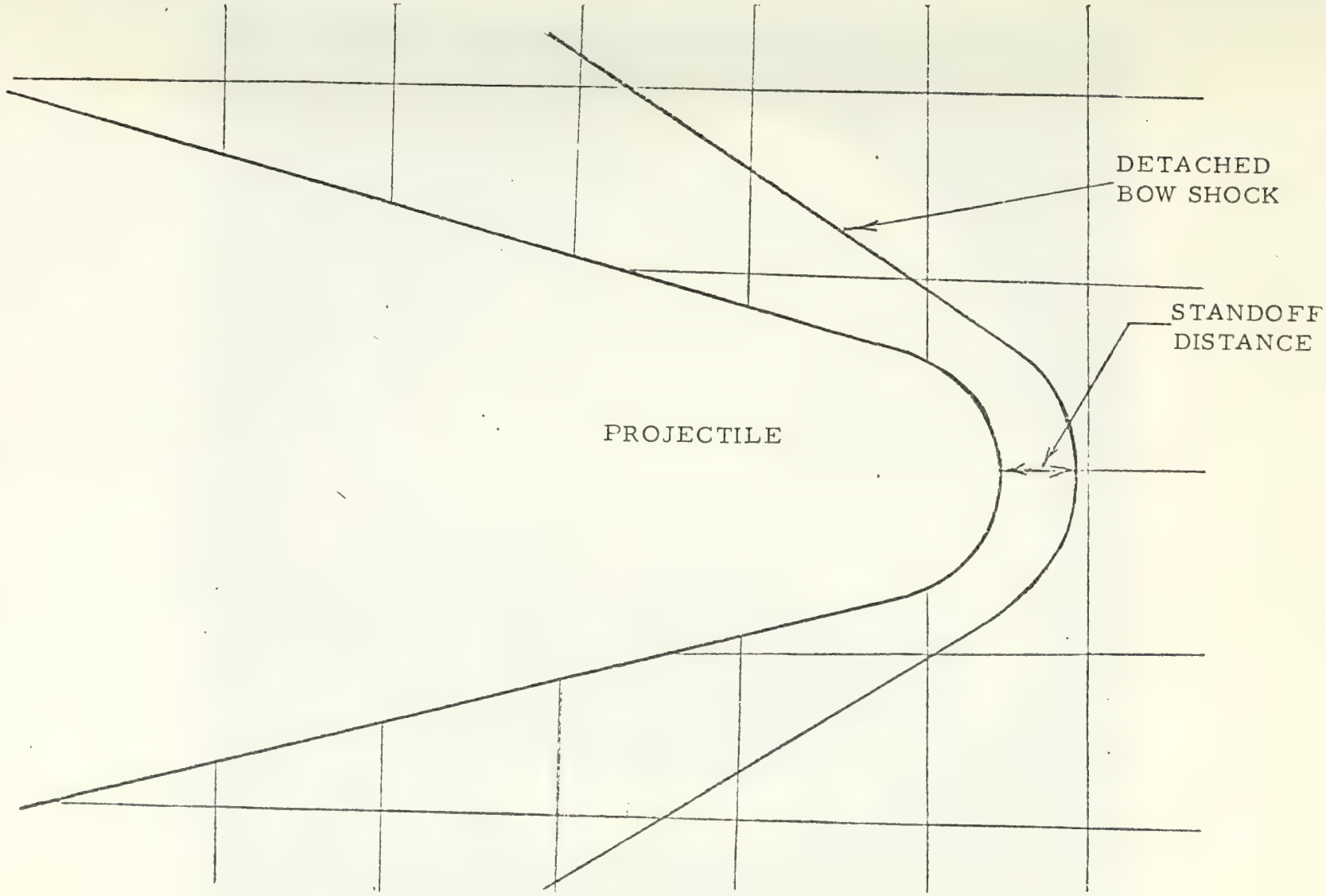


FIGURE 13. REDRAWN BOW SHOCK OF FIGURE 12

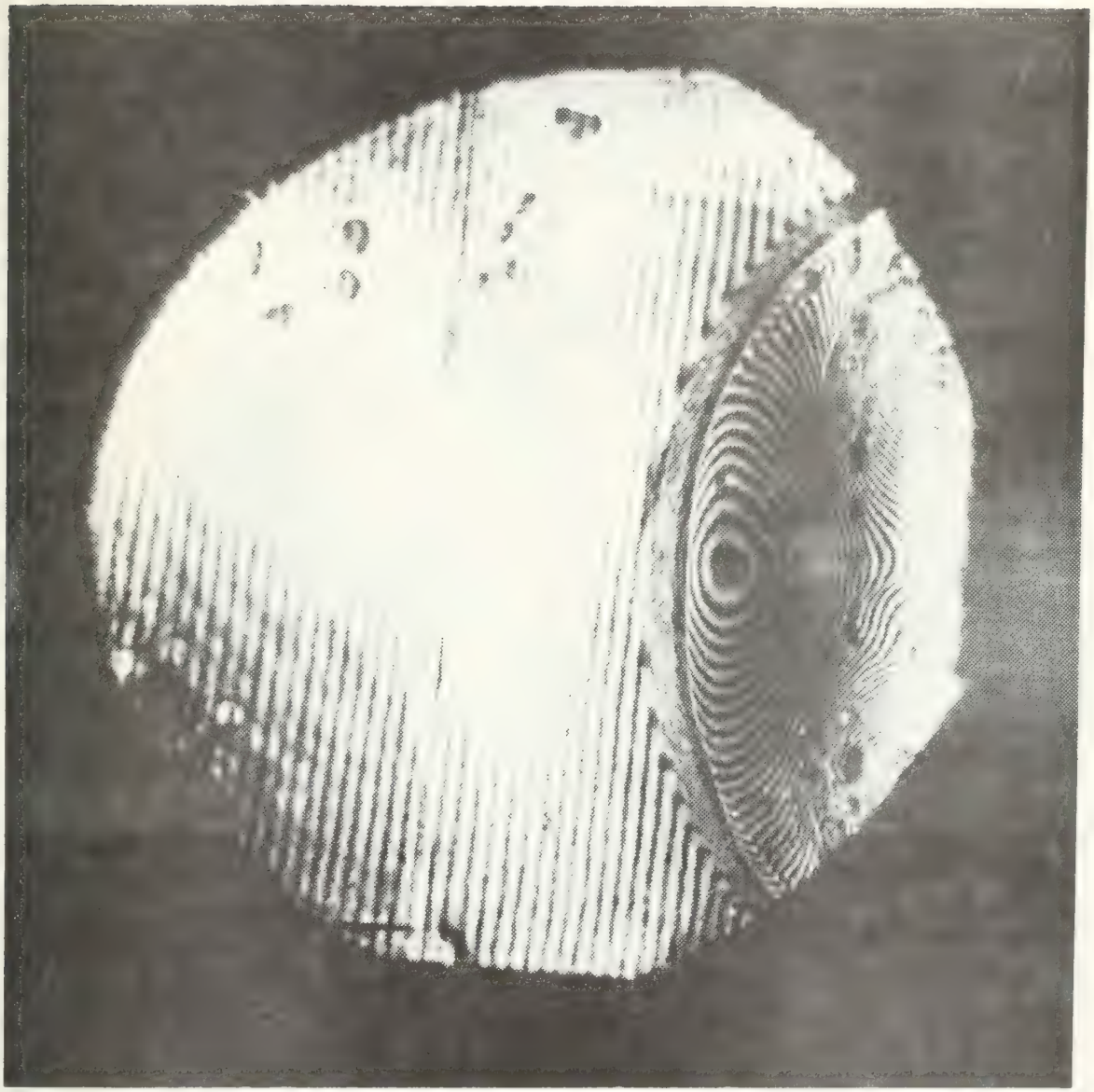


FIGURE 14. HOLOGRAPHIC INTERFEROGRAM OF PRECURSOR TRAVELING SHOCK

FIGURE 15. HOLOGRAPHIC INTERFEROGRAM OF PRECURSOR TRAVELING SHOCK

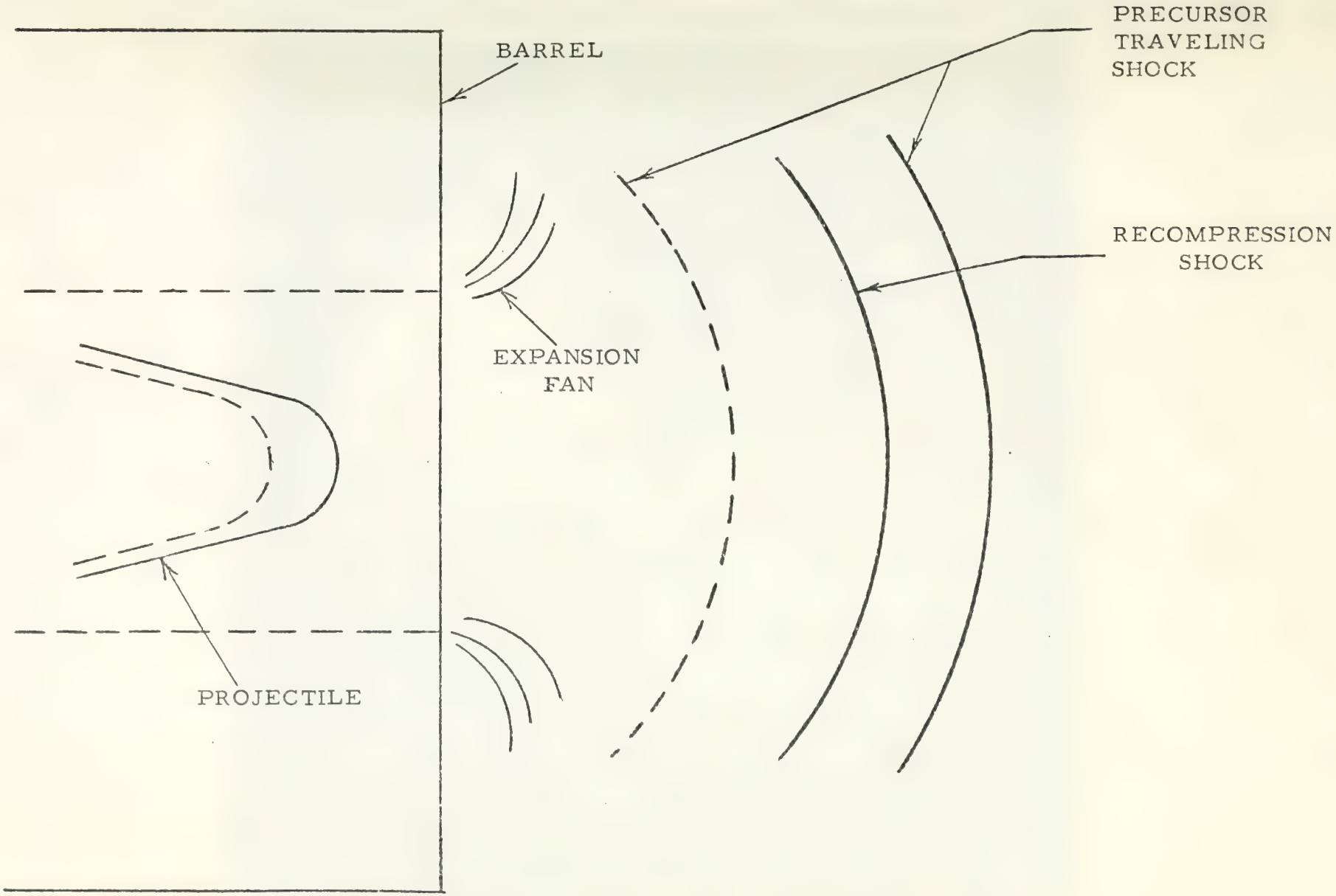


FIGURE 16. REDRAWN SHOCK SYSTEMS OF FIGURES 14 AND 15

FIGURE 17. DOUBLE PULSED HOLOGRAM OF PROJECTILE

FIGURE 18. HOLOGRAPHIC INTERFEROGRAM OF PROJECTILE

FIGURE 19. HOLOGRAPHIC INTERFEROGRAM OF PROJECTILE

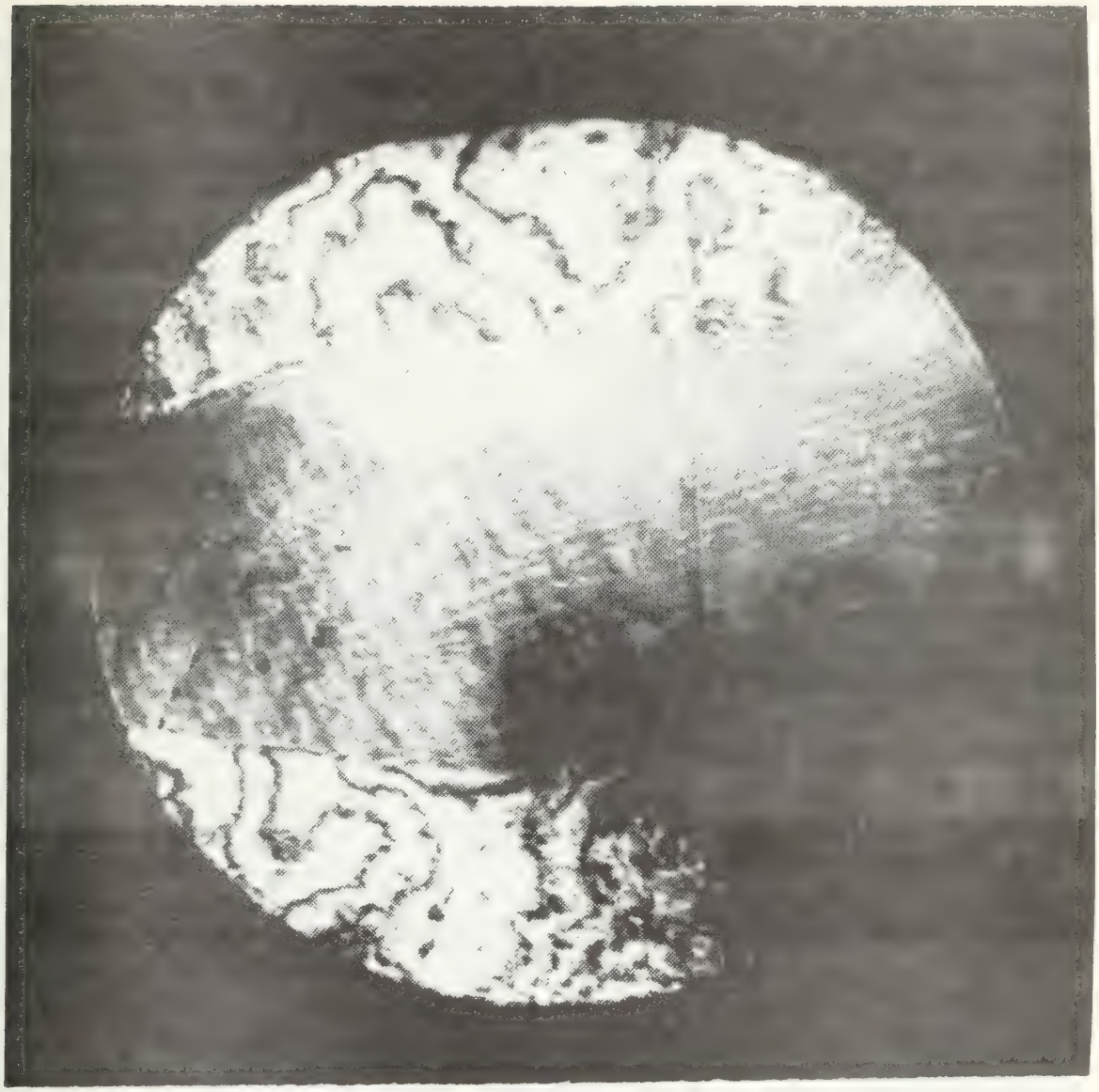


FIGURE 20. HOLOGRAPHIC INTERFEROGRAM OF PROJECTILE

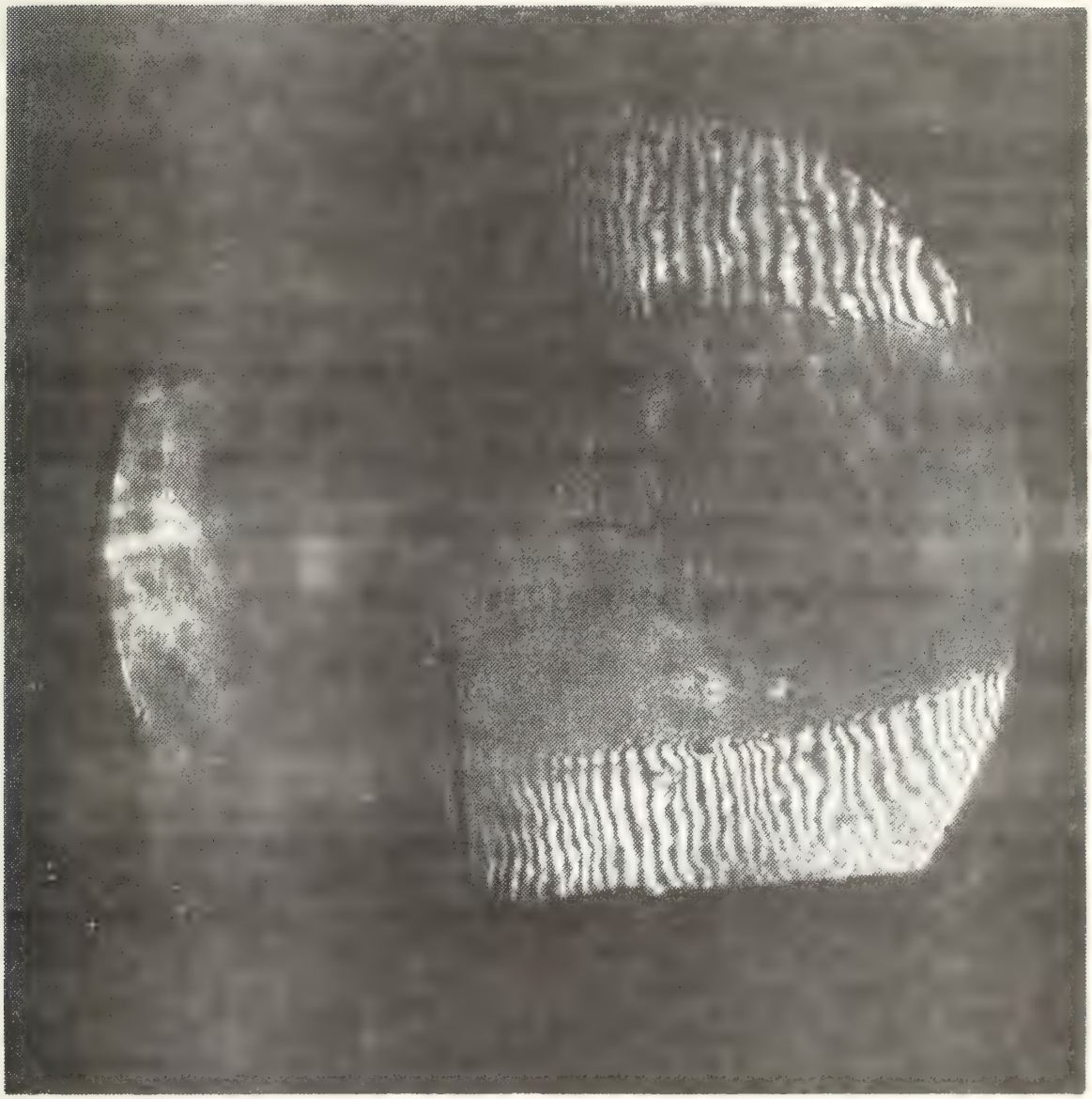


FIGURE 21. HOLOGRAPHIC INTERFEROGRAM OF PROJECTILE

GUN BARREL PROJECT

Computer Run Number: 3 Date: 5/10/75

Dimensions: 6 Regions, 6 Zones

Regions	Zones	Length (cm)	Area (cmsq)	Volume (cc)
1	1	1.47	2.95	4.35
2	1	1.47	2.95	4.35
3	1	1.47	2.95	4.35
4	1	1.47	2.95	4.35
5	1	1.47	2.95	4.35
6	1	5.40	2.95	15.93

INITIAL CONDITIONS

Powder Conditions: Grams Powder = 38.23
TBURND = 1.000 Millisec

Materials:

Region	NEQST	Pressure (psi)	Temp. (Deg. K)	Molec. Wt. (gm/mole)
1	2	14.7	300.0	125.00
2	2	14.7	300.0	125.00
3	2	14.7	300.0	125.00
4	2	14.7	300.0	125.00
5	2	14.7	300.0	125.00
6	3		300.0	55.85

Print out every 0.20 millisec up to 10.00 millisec
Print out every 0.050 millisec up to break
Print out every 0.200 millisec up to launch

Mass of Projectile	=	90.0 gm
Break Valve Strength	=	690.0 Bars
Number of Pressure Points:		1
Location of Pressure Points:		14.0 cm

FIGURE 22. COMPUTER OUTPUT FORMAT

GUN BARREL PROJECT

Cycle 290 T(Millisec) 1.88443E 00
DT(Millisec) 2.18257E-02

j	X (CM)	VELOCITY (CM/MS)	PRESSURE (BARS)
1	0.0	0.0	1.01381E 03
2	1.46490E 02	1.01004E 02	8.52849E 02
3	1.47602E 02	1.03653E 02	7.78181E 02
4	1.48734E 02	1.06449E 02	8.85098E 02
5	1.49668E 02	1.07232E 02	1.05442E 03
6	1.50551E 02	1.06399E 02	3.98267E 02

FIGURE 23. COMPUTER OUTPUT FORMAT

FIGURE 24. PROJECTILE VELOCITY vs. POSITION

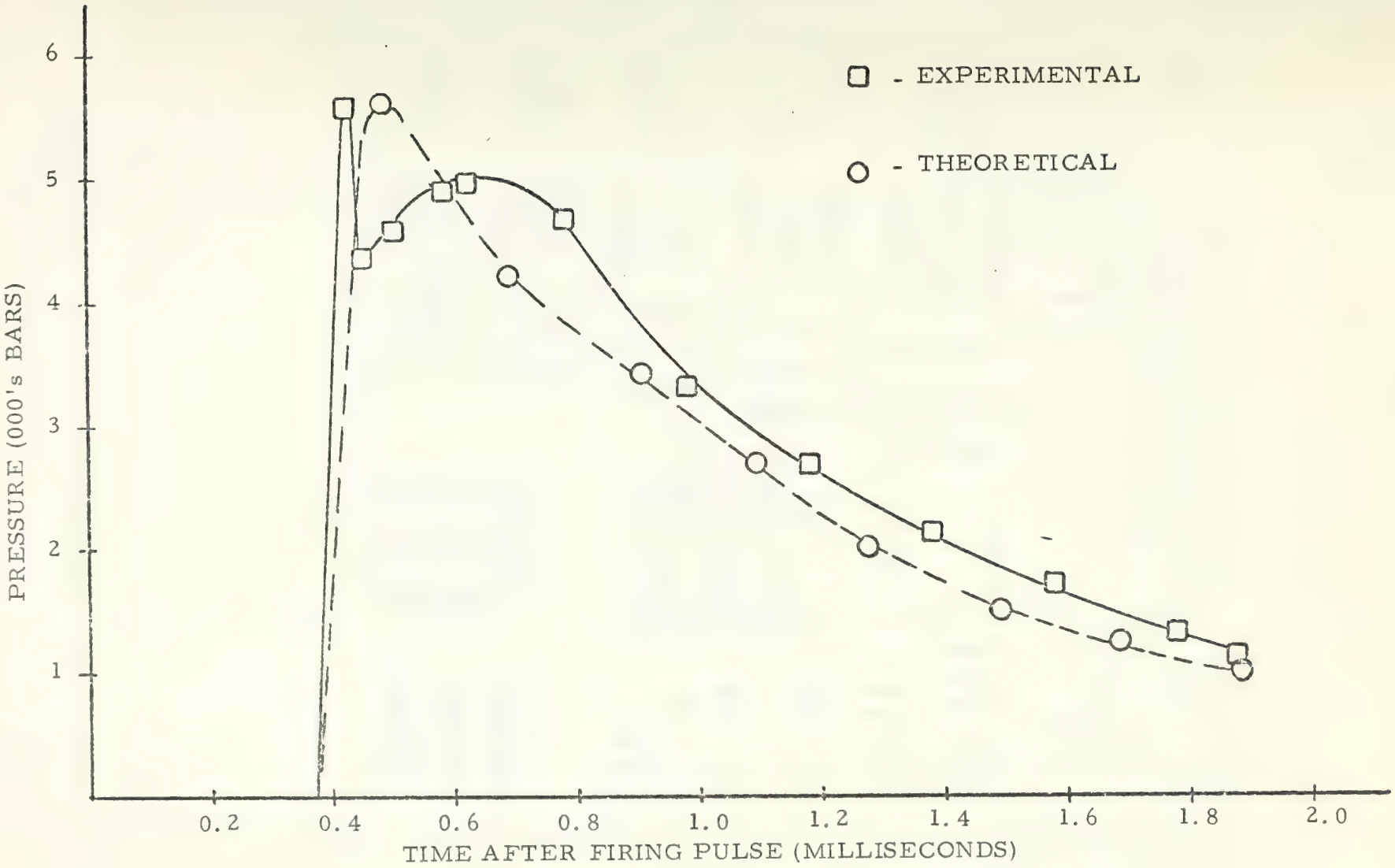


FIGURE 25. PRESSURE (14 cm FROM BREECH) vs. TIME

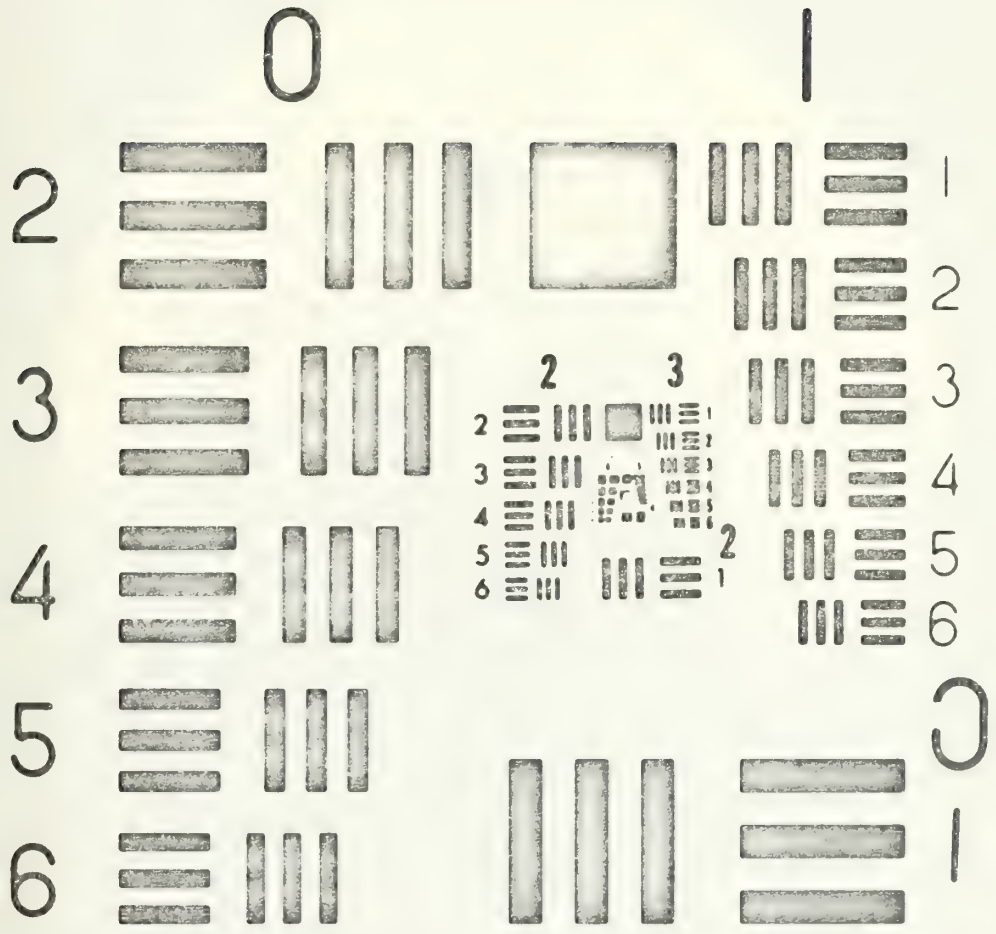


FIGURE 26. USAF 1951 RESOLUTION TEST TARGET

FIGURE 27. HOLOGRAM OF USAF 1951 RESOLUTION TEST TARGET

GUN PROJECT

```
C     MAIN PROGRAM                                                                  HNMN0010
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL                    HVMN0020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXHVMN0030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,HVMN0040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  HVMN0050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    HVMN0060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,         HVMN0070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    HVMN0080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   HVMN0090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      HVMN0100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   HVMN0110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   HVMN0120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      HVMN0130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   HVMN0140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),HVMN0150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),HVMN0160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         HVMN0170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)HVMN0180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   HVMN0190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   HVMN0200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),HVMN0210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    HVMN0220
      DIMENSION XP1(500), XP2(500), PP1(500), VP2(500),XP3(500),PP3(500)HVMN0230
      DIMENSION XPO(10), ISTOPX(10), NPTPL(10),                 TPOX(500),HVMN0240
     1PPLT(500), TPLT(500)                                                 HVMN0250
      DIMENSION ISTORM(100), STORM(100),AVEL(100),ALOAD(100),AGAS(100)     HVMN0260
      DIMENSIONXP4(500),PP4(500)                                           HVMN0270
      DIMENSION DATA(150),PRSTAB(90)                                       HVMN0280
      DIMENSION PMDMAX(200), TMDMAX(200), PMDMIN(200), TMDMIN(200)         HVMN0290
      NAMELIST/READ1/AMOL,AREA1,AREA2,AREA3,CALPGM,CQSQX4,EMLEAD,          HVMN0300
     1EMPIST,EMPROJ,FRAC,GAMMA,GASPRS,GMSPDR,HYDRD1,HYDRD2,IHEL,IMAX,     HVMN0310
     2INU,IPOX,JPROJ,NCHEKE,NDATE1,NDATE2,NDATE3,NEQST,NPOX,NUMBER,       HVMN0320
     3NZONES,OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PCON3,PO,PVERR,PVWANT,      HVMN0330
     4R,RADIUS,SHPR,SLOPE,TBURND,TMAX1,TMAX2,TO,UZERO,XPO,XPV1,XPV2,      HVMN0340
     5XSTOP                                                               HVMN0350
C     INITIAL CONDITIONS FOR PROGRAM                                       HVMN0370
      T=0.0                                                               HVMN0375
      IDATA=0                                                             HVMN0380
```

```
  123 NI =0                                                                      HVMN0390
      M=6                                                                        HVMN0400
       NPVITR = 1                                                                HVMN0410
    1 CALL ZEOAB                                                                HVMN0420
      CALL ZEROA(500,XP1,XP2,PP1,VP2,XP3)                                       HVMN0430
      CALL ZEROA(500,PP3,PP1,PP1,PP1,PP1)                                       HVMN0440
      CALL ZEROA(10,ISTOPX,ISTOPX,ISTOPX,ISTOPX,ISTOPX)                         HVMN0450
      INTERJ(31)=M                                                              HVMN0460
      CPMAX=0.0                                                                 HVMN0470
       PTMAX=0.0                                                                HVMN0480
      AMPMAX=0.0                                                                HVMN0490
      NTIMPT=0                                                                  HVMN0500
      IP=0                                                                      HVMN0510
      NPUNCH=1                                                                  HVMN0520
      IPNCHX=0                                                                  HVMN0530
      LN = 0                                                                    HVMN0540
      IPV1 = 1                                                                  HVMN0550
      IPV2 = 2                                                                  HVMN0560
      HYDRD1=13.3                                                               HVMN0565
      HYDRD2=.1                                                                 HVMN0566
C     END INITIAL CONDITIONS FOR PROGRAM, BEGIN INPUT FOR RUN,NEW OR ITE        HVMN0570
       IF ( NPVITR.EQ.1)  GO TO 41                                              HVMN0580
      NPVITR = 1                                                                HVMN0590
C     INPUT FOR ITERATION FROM STORAGE                                          HVMN0600
  620 CALL STORE (ISTORM, STORM)                                                HVMN0610
      EMLEAD=STORM(97)                                                          HVMN0620
      HYDRD1 = STORM(98)                                                        HVMN0630
      HYDRD2 = STORM(99)                                                        HVMN0640
      NEQST(30) = ISTORM (100)                                                  HVMN0650
      IF(IDATA)8,8,608                                                          HVMN0660
   41  CONTINUE                                                                 HVMN0670
C     INPUT FOR NEW RUN, STORAGE OF INPUT                                       HVMN0680
      READ(5,604)IDATA,IPRNTZ,ITRNSF,IPUNCH,DTSQ(199)                           HVMN0690
  604 FORMAT(4I3,F10.0)                                                         HVMN0700
      IF(ITRNSF.EQ.0) GO TO 619                                                 HVMN0710
      M=6                                                                       HVMN0720
      INTERJ(31)=M                                                              HVMN0730
  619 IF(IDATA)606,606,620                                                      HVMN0740
  608 READ(5,READ1)                                                             HVMN0750
      IDATA=0                                                                   HVMN0760
      GO TO 610                                                                 HVMN0770
  606 CALL READ                                                                 HVMN0780
      READ(5,20) IPOX, NPOX,(XPO(K), K=1, NPOX)                                 HVMN0790
      READ(5, 49) XPV1, XPV2, PVERR, PVWANT                                     HVMN0800
      READ(5,6)R,EMPIST, FRAC, EMLEAD                                           HVMN0810
    6 FORMAT(E10.4,3F10.0)                                                      HVMN0820
      READ (5,49) (PO(I),I=1,IMAX)                                              HVMN0830
      READ (5,49) (TO(I),I=1,IMAX)                                              HVMN0840
```

```
      READ (5,49) (AMOL(I),I=1,IMAX)                                    HVMN0850
   49 FORMAT(7F10.0)                                                     HVMN0860
  610 CONTINUE                                                           HVMN0870
      CALL STORIN (ISTORM, STORM)                                        HVMN0880
      STORM(97)=EMLEAD                                                   HVMN0890
      STORM(98)=HYDRD1                                                   HVMN0900
      STORM(99)=HYDRD2                                                   HVMN0910
      ISTORM(100) = IPOX                                                 HVMN0920
C     INITIAL CONDITIONS AND CONSTANTS FOR RUN                           HVMN0930
    8 NPTN=NZONES(1)+NZONES(2)+NZONES(3)+1                               HVMN0940
      XSST = FRAC * OUTBDY(5)                                            HVMN0950
      NEQST(30) = IPOX                                                   HVMN0960
  616 CALL CALCUL (EMLEAD)                                               HVMN1110
      IF(NI.NE.0)GO TO 603                                               HVMN1120
      CALL PRINTC(EMLEAD,FRAC,XPV1,XPV2,PVWANT,NPOX,IPOX,XPO)            HVMN1130
      IF(IPRNTZ.EQ.0)GO TO 603                                           HVMN1140
      READ(5,11)ILASTK                                                   HVMN1150
      IF(ILASTK)123,12,1                                                 HVMN1160
  603 CALL SETUP                                                         HVMN1170
      DO 706 IMP=1, JLAST                                                HVMN1180
      PMDMIN(IMP)=PPLUSQ(IMP)                                            HVMN1190
  706 PMDMAX(IMP)=PPLUSQ(IMP)                                            HVMN1200
C     MAIN LOOP OF PROGRAM - DYNMEQ, LFTOVER, AND OUTPUT                 HVMN1210
    2 CALL DYNMEQ                                                        HVMN1220
      CALL LFTOVR(IPNCHX)                                                HVMN1230
      DO 710 IMP=1, JLAST                                                HVMN1240
      IF(PPLUSQ(IMP).GT.PMDMIN(IMP))  GO TO 705                          HVMN1250
      PMDMIN(IMP)=PPLUSQ(IMP)                                            HVMN1260
      TMDMIN(IMP)=T                                                      HVMN1270
  705 IF(PPLUSQ(IMP).LT.PMDMAX(IMP))   GO TO 710                         HVMN1280
      PMDMAX(IMP)=PPLUSQ(IMP)                                            HVMN1290
      TMDMAX(IMP)=T                                                      HVMN1300
  710 CONTINUE                                                           HVMN1310
      IF(IPUNCH.EQ.0.OR.JPROJ.NE.300) GO TO 627                          HVMN1320
      PRSTAB(NPUNCH)=T-DTSQ(200)                                         HVMN1330
      NPNP1=NPUNCH+1                                                     HVMN1340
      JPLHAF=INTERJ(6)                                                   HVMN1350
      J=JPLHAF                                                           HVMN1360
      JMNHAF=JPLHAF-1                                                    HVMN1370
      DUD1=26./18.*PPLUSQ(JMNHAF)-1./9.*PPLUSQ(JMNHAF-1)                 HVMN1380
  707 PRSTAB(NPNP1)=DUD1                                                 HVMN1390
      IF(T.GT.(DTSQ(200)+DTSQ(199))) GO TO 647                           HVMN1400
      PRSTAB(NPNP1)=PRSTAB(NPNP1)*(T-DTSQ(200))/DTSQ(199)                HVMN1410
  647 NPUNCH=NPUNCH+2                                                    HVMN1420
      IF(91-NPUNCH)625,625,627                                           HVMN1430
  625 PUNCH 641, PRSTAB                                                  HVMN1440
  641 FORMAT(3(F12.8,E12.8))                                             HVMN1450
      NPUNCH=1                                                           HVMN1460
```

```
  627 CONTINUE                                                                  HVMN1470
  630 M=6                                                                       HVMN1480
   72 CONTINUE                                                                  HVMN1880
C     STORAGE OF MAXIMUM PRESSURES                                            HVMN1890
      INER51 = INTERJ(6) -1                                                   HVMN1900
      CPMAX=AMAX1(CPMAX,PPLUSQ(NPTN))                                         HVMN1910
       PTMAX=AMAX1(PTMAX, PPLUSQ(NPTN-1),PPLUSQ(NPTN-2),PPLUSQ(NPTN-3))       HVMN1920
      AMPMAX=AMAX1(AMPMAX,PPLUSQ(INER51))                                     HVMN1930
C     DETERMINATION IF MODEL HAS BEEN LAUNCHED                                HVMN1940
      IF(XSTOP-X(JLAST,NPLUS1)) 9, 3,3                                        HVMN1950
C     ROUTINE STORAGE OF POINTS TO BE PLOTTED                                 HVMN1960
    3 IF(IPOX.EQ.5)  GO TO 2                                                  HVMN1970
      IF ( X(NPTN, N) . LT . XSST )  GO TO 2                                  HVMN1980
      KN=NCYCLE/6                                                             HVMN1990
      QN = KN                                                                 HVMN2000
      SN=NCYCLE                                                               HVMN2010
      TN=SN/6.                                                                HVMN2020
      IF(TN-QN) 4, 4, 2                                                       HVMN2030
    4 IF(LN.GT.498) GO TO 7                                                   HVMN2040
      LN = LN+ 1                                                              HVMN2050
      IF (IPOX.EQ.6) GO TO 75                                                 HVMN2060
      XP3(LN)=T                                                               HVMN2070
      PP3(LN)=PPLUSQ(NPTN)                                                    HVMN2080
       XP4(LN)=X(NPTN-1, N)                                                   HVMN2090
       PP4(LN)=PPLUSQ(NPTN-1)                                                 HVMN2100
      IF(IPOX.EQ.1) GO TO 51                                                  HVMN2110
      DO 60  INPOX=1, NPOX                                                    HVMN2120
      IF(ISTOPX(INPOX).GE.1) GO TO 60                                         HVMN2130
      NTINPT=LN                                                               HVMN2140
      DO 58 INPTN=2,JLAST1                                                    HVMN2150
      IF(XPO(INPOX).LT.X1(INPTN)) GO TO 59                                    HVMN2160
   58 CONTINUE                                                                HVMN2170
      DUMVAR(LN,INPOX)=PPLUSQ(INER51)                                         HVMN2180
      NPTPL(INPOX)=LN                                                         HVMN2190
      GO TO 60                                                                HVMN2200
   59 DUMVAR(LN,INPOX)=PPLUSQ(INPTN-1)+(PPLUSQ(INPTN-1)-PPLUSQ(INPTN))        HVMN2210
     1/(X1(INPTN-1)-X1(INPTN))*(XPO(INPOX)-X1(INPTN-1))                       HVMN2220
      NPTPL(INPOX)=LN                                                         HVMN2230
      IF(LN.EQ.1099)GO TO 55                                                  HVMN2240
      GO TO 60                                                                HVMN2250
   55 ISTOPX(INPOX)=2                                                         HVMN2260
      NPTPL(INPOX)=LN                                                         HVMN2270
   60 CONTINUE                                                                HVMN2280
      IF (IPOX.NE.6) GO TO 78                                                 HVMN2290
   75 DUMVAR(LN,1) =PPLUSQ(INER51)                                            HVMN2300
   78 TPOX(LN)=T                                                              HVMN2310
      IF (IPOX.EQ.6) GO TO 2                                                  HVMN2320
   51 IF(IPOX.EQ.2) GO TO 52                                                  HVMN2330
```

```
C       PROGRAM TO FIND MAX IN REGION TO GO HERE                                HVMN2340
   52   CONTINUE                                                                HVMN2350
C       STORAGE OF MODEL PLOTS AFTER BREAK VALVE                                HVMN2360
    7   IF(JPROJ-300) 13,5,13                                                   HVMN2370
    5   IF(IP.GT.498) GO TO 2                                                   HVMN2380
        IP=IP+1                                                                 HVMN2390
        IF(XSTOP.EQ.3000.) GO TO 76                                             HVMN2400
   10   XP1(IP)=X(JLAST,N)                                                      HVMN2410
        XP2(IP)=X(JLAST,N)                                                      HVMN2420
        PP1(IP)=PPLUSQ(INER51)                                                  HVMN2430
        VP2(IP)=U(JLAST, NMNHAF)                                                HVMN2440
   13   GO TO 2                                                                 HVMN2450
C       POINT OF RETURN TO MAIN LOOP OF PROGRAM                                 HVMN2460
C       FINAL STORAGE OF POINTS TO BE PLOTTED, AND WRITING OF ALL PLOT TAP      HVMN2470
    9   IF (IPCX.EQ.5) GO TO  25                                                HVMN2480
        IF (IPCX.EQ.6) GO TO 76                                                 HVMN2490
        IP=IP+1                                                                 HVMN2500
        XP1(IP)=X(JLAST,N)                                                      HVMN2510
        XP2(IP)=X(JLAST,N)                                                      HVMN2520
        PP1(IP)=PPLUSQ(INER51)                                                  HVMN2530
        VP2(IP)=U(JLAST,NMNHAF)                                                 HVMN2540
        GO TO 36                                                                HVMN2630
   35   NPOX=1                                                                  HVMN2640
   36   DO 70 IPLTXT=1,NPOX                                                     HVMN2650
        NPTTX=NPTPL(IPLTXT)                                                     HVMN2660
        IF(NPTTX.LT.10) GO TO 70                                                HVMN2670
        NPTTT=NPTPL(IPLTXT)                                                     HVMN2680
        DO 80 ITXP=1,NPTTT                                                      HVMN2690
        TPLT(ITXP)=TPOX(ITXP)                                                   HVMN2700
   80   PPLT(ITXP)=DUMVAR(ITXP, IPLTXT)                                         HVMN2710
        IF(JPROJ.NE.300) GO TO 1                                                HVMN2740
   70   CONTINUE                                                                HVMN2750
        GO TO 25                                                                HVMN2760
   76   DO 93 ITXP=1, LN                                                        HVMN2770
        PPLT(ITXP) = DUMVAR (ITXP,1)                                            HVMN2780
   93   CONTINUE                                                                HVMN2790
C       TERMINATION OF RUN, RETURN FOR NEW INPUT                                HVMN2810
   25   READ(5,11) ILASTK                                                       HVMN2820
        IF((IPUNCH.EQ.0).OR.(NPUNCH.EQ.1))  GO TO 629                           HVMN2830
        NPUNCH=NPUNCH-1                                                         HVMN2840
        PUNCH 641, (PRSTAB(IPXX), IPXX=1,NPUNCH)                                HVMN2850
  629   CONTINUE                                                                HVMN2860
        WRITE(6, 45) CPMAX, PTMAX, AMPMAX                                       HVMN2870
        WRITE(6,704) ((IT,PMDMIN(IT),TMDMIN(IT),PMDMAX(IT),TMDMAX(IT)),        HVMN2880
       1IT=1,JLAST)                                                             HVMN2890
  704   FORMAT(I3,2X,E12.6,2X,E12.6,2X,E12.6,2X,E12.6)                          HVMN2900
   45   FORMAT(3F20.2)                                                          HVMN2910
        IF(ILASTK) 15, 12, 1                                                    HVMN2920
```

```
15 WRITE(6,44)(NI,((AVEL(I),ALOAD(I),AGAS(I)),I=1,NI))                  HVMN2930
   GO TO 123                                                            HVMN2940
12 STOP                                                                 HVMN2950
20 FORMAT (2I2,7F10.0)                                                  HVMN2960
44 FORMAT(I3/(3F10.0))                                                  HVMN2970
11 FORMAT(I3)                                                           HVMN2980
   END                                                                  HVMN2990
```

```
      SUBROUTINE READ                                                    READ0010
C     READ DIMENSIONS, INITIAL CONDITIONS, AND POWDER PARAMETERS         READ0015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL         READ0020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXREAD0030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,READ0040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  READ0050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    READ0060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        READ0070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    READ0080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   READ0090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      READ0100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   READ0110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   READ0120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      READ0130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   READ0140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),READ0150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),READ0160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         READ0170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)READ0180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   READ0190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   READ0200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),READ0210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    READ0220
    1 FORMAT(20I3)                                                       READ0230
    2 FORMAT(F10.0,I5)                                                   READ0240
    3 FORMAT(7F10.0)                                                     READ0250
      READ(5,1) IMAX,NDATE1,NDATE2,NDATE3,NUMBER,NCHEKE,INU,JPROJ        READ0260
      READ(5,1) (NEQST(I),I=1,IMAX)                                      READ0270
      READ(5,1) (NZONES(I),I=1,IMAX)                                     READ0280
      READ(5,3) (OUTBDY(I),I=1,IMAX)                                     READ0290
      READ(5,3) (GAMMA(I),I=1,IMAX)                                      READ0300
      READ(5,3) (CQSQX4(I),I=1,IMAX)                                     READ0310
      READ(5,3) AREA1,AREA2,AREA3,PCON1,PCON2,SHPR,EMPROJ                READ0320
      READ(5,3) OUTDT1,TMAX1,OUTDT2,TMAX2,XSTOP                          READ0330
    8 IF(INU) 9,901,9                                                    READ0340
    9 READ(5,3) (UZERO(I),I=1,IMAX)                                      READ0350
      GO TO 904                                                          READ0360
  901 DO 902 I=1,IMAX                                                    READ0370
  902 UZERO(I)=0.                                                        READ0380
  904 READ(5,100)PCON3,SLOPE,RADIUS                                      READ0390
      READ(5,5)CALPGM,TBURND,GMSPDR,GASPRS,IHEL                          READ0400
  123 FORMAT(2E15.5)                                                     READ0420
    5 FORMAT(4F10.0,I4)                                                  READ0430
  100 FORMAT(7F10.0)                                                     READ0440
  903 RETURN                                                             READ0450
      END                                                                READ0460
```

```
      SUBROUTINE PRINTO(EMLEAD,FRAC,XPV1,XPV2,PVWANT,NPOX,IP,XPO)                0
C     PRINT DIMENSIONS AND POWDER CONDITIONS                                     0
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL                 0
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAX         0
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,         0
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,          0
     3ENRGNG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDPD1,HYDPD2,HYDRD3,HYDRAD,            0
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,                0
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,           0
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,          0
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP             0
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,           0
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,          0
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,             0
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR          0
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),         0
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),        0
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),                0
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)        0
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),          0
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),          0
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),        0
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                           0
      DIMENSION XLGTH(30),ZQMASS(30),XPO(10),REGVOL(30)                         0
      WRITE(6,65)                                                               0
   65 FORMAT(1H1)                                                               0
      XLGTH(1)=OUTBDY(1)                                                        0
      REGVOL(1)=AREA1*XLGTH(1)                                                  0
      IF(IMAX.EQ.1) GO TO 210                                                   0
      DO 200 KQX=2,IMAX                                                         0
  200 XLGTH(KQX)=OUTBDY(KQX)-OUTBDY(KQX-1)                                      0
      KQXX=IMAX-1                                                               0
      DO 201 KQX=2,KQXX                                                         0
  201 REGVOL(KQX)=AREA2*XLGTH(KQX)                                              0
      REGVOL(IMAX)=AREA3*XLGTH(IMAX)                                            0
  210 ANGLE=ATAN(SLOPE)                                                         0
      ANGLE=ANGLE*(360./6.2832)                                                 0
      WRITE (6,100) NUMBER,NDATE1,NDATE2,NDATE3                                 0
      WRITE (6,102) IMAX,JPROJ                                                  0
      I=1                                                                       0
      WRITE (6,103) I,NZONES(I),XLGTH(I),AREA1,REGVOL(I)                        0
      IF(IMAX.EQ.1) GO TO 211                                                   0
      KQX=IMAX-2                                                                0
      WRITE (6,103) (I,NZONES(I),XLGTH(I),AREA2,REGVOL(I),I=2,KQX)              0
      KQX=IMAX-1                                                                0
      WRITE (6,104) KQX,NZONES(KQX),XLGTH(KQX)                                  0
      WRITE (6,103) IMAX,NZONES(IMAX),XLGTH(IMAX),AREA3,REGVOL(IMAX)            0
  211 WRITE (6,105) SLOPE,ANGLE                                                 0
```

```
      WRITE (6,111) CALPGM,TBURND,GMSPDR,GASPRS                          0
      WRITE (6,106)                                                      0
      WRITE (6,108) (I,NEQST(I),PO(I),TO(I),AMOL(I),CQSQX4(I),I=1,IMAX)  0
      WRITE (6,109)                                                      0
      WRITE (6,110) (I,GAMMA(I),EZERO(I),ROZERO(I),VZERO(I),I=1,IMAX)    0
      WRITE (6,124) R                                                    0
      WRITE (6,114) XPV1,XPV2,PVWANT                                     0
      WRITE (6,115) OUTDT1,TMAX1,OUTDT2,TMAX2                            0
      EMLEAX=EMLEAD*453.59                                               0
      EMPISX=EMPIST*453.59                                               0
      XXMAS=REGVOL(IMAX)*ROZERO(IMAX)                                    0
      SHPRX=SHPR*14.504                                                  0
      WRITE(6,112) EMLEAD,EMLEAX,EMPIST,EMPISX,XXMAS                     0
      WRITE (6,113) SHPR,SHPRX                                           0
      KQX=IPOX+1                                                         0
      GO TO (10,11,12,12,12,13,14),KQX                                   0
   10 WRITE (6,119) IPOX                                                 0
      GO TO 15                                                           0
   11 WRITE (6,120) IPOX                                                 0
      GO TO 15                                                           0
   12 WRITE (6,123) IPOX                                                 0
      GO TO 15                                                           0
   13 WRITE (6,121) IPOX                                                 0
      GO TO 15                                                           0
   14 WRITE (6,122) IPOX                                                 0
   15 WRITE (6,116) NPOX                                                 0
      WRITE (6,117) (XPO(I),I=1,NPOX)                                    0
      WRITE (6,118) FRAC                                                 0
      WRITE(6,65)                                                        0
      RETURN                                                             0
  100 FORMAT(23X,36HHYPERVELOCITY MODEL LAUNCHER PROGRAM//22X,19HCOMPUTE  0
     1R RUN NUMBER,I5,7H  DATE ,I2,1H/,I2,1H/,I2)                        0
  102 FORMAT(1H /34X,14HGUN DIMENSIONS/31X,I2,10H REGIONS  , I3,6H ZONES  0
     1//12X,6HREGION,5X,5HZONES,6X,6HLENGTH,9X,4HAREA,11X,6HVOLUME/35X,4  0
     2H(CM), 9X,6H(CMSQ),11X,4H(CC)/1H )                                 0
  103 FORMAT(14X,I2,9X,I2,2X,F10.2,5X,F10.2,7X,F10.2)                    0
  104 FORMAT(14X,I2,9X,I2,2X,F10.2,11X,3H---,12X,3H---)                  0
  105 FORMAT(1H /19X,7HSLOPE =,F8.4,9X,7HANGLE =,F6.2,5H  DEG)           0
  106 FORMAT(1H /5X,12HMATERIALS --//7X,6HREGION,5X,5HNEQST,5X,8HPRESSUR  0
     1E,7X,4HTEMP,9X,8HMOLEC WT,6X,6HCQSQX4/30X,5H(PSI),6X,7H(DEG K),7X,  0
     29H(GM/MOLE)/1H )                                                   0
  108 FORMAT(9X,I2,8X,I2,5X,F9.2,6X,F7.2,6X,F9.4,6X,F5.1)                0
  109 FORMAT(1H /6X,6HREGION,4X,5HGAMMA,9X,6HENERGY,10X,7HDENSITY,9X,9HS  0
     1P VOLUME/26X,13H(BARS-CC/CC0),7X,7H(GM/CC),9X,8H(CC/CC0)/1H )       0
  110 FORMAT(8X,I2,5X,  F6.3,6X,  E11.4,6X,E11.4,6X,E11.4)               0
  111 FORMAT(1H //32X,18HINITIAL CONDITIONS/5X,20HPOWDER CONDITIONS --//  0
     114X,8HCALPGM =,F12.4,6X,8HTBURND =,F12.4,6H  MSEC/14X,8HGMSPDR =,F  0
     212.4,6X,8HGASPRS =,F12.4,5H  PSI)                                  0
```

```
112 FORMAT(1H /5X,10HWEIGHTS --//9X,6HPISTON/13X,23HMASS OF FIRST SECT
   1ICN =,F13.4,4H  LB,8X,1H=,F13.4,4H  GM/13X,24HMASS OF SECOND SECTI
   2CN =,F12.4,4H  LB,8X,1H=,F13.4,4H  GM//9X,5HMODEL/13X,15HMASS OF M
   3ODEL =,F12.4,4H  GM)
113 FORMAT(1H /18X,22HBREAK VALVE STRENGTH =,F10.2,6H  BARS,5X,1H=,F10
   1.2,5H  PSI)
114 FORMAT(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H  CM   ,
   110X,6HXPV2 =,F10.2,7H  CM   /10X,18HDESIRED VELOCITY =,F10.2,7H FT
   2/SEC)
115 FORMAT(2H  //20X,15HPRINT OUT EVERY,F7.3,11H MSEC UP TO,F7.3,5H MS
   1EC/20X,15HPRINT OUT EVERY,F7.3,17H MSEC UP TO BREAK/20X,15HPRINT O
   2UT EVERY,F7.3,18H MSEC UP TO LAUNCH)
116 FORMAT(1H /10X,26HNUMBER OF PRESSURE POINTS ,I4//10X,27HLOCATION O
   1F PRESSURE POINTS)
117 FORMAT (20X,F10.0,5H   CM)
118 FORMAT(1H /10X,20HPLOT START FRACTION ,1PE11.4)
119 FORMAT(1H //5X,8HPLOTS --,10X,6HIPOX =,I3,34H  (ALL PLOTS, ALL PRE
   1SSURE POINTS))
120 FORMAT(1H //5X,8HPLOTS --,10X,6HIPOX =,I3,33H  (ALL PLOTS, NO PRES
   1SURE POINTS))
121 FORMAT(1H //5X,8HPLOTS --,10X,6HIPOX =,I3,12H  (NO PLOTS))
122 FORMAT(1H //5X,8HPLOTS --,10X,6HIPOX =,I3,24H  (ONLY PRESSURE POIN
   1TS))
123 FORMAT(1H //5X,8HPLOTS --,10X,6HIPOX =,I3)
124 FORMAT(1H /6X,3HR =,1PE11.4)
    RETURN
    END
```

```
      SUBROUTINE SETUP                                                  SETU0010
C   SETS INITIAL CONDITIONS FOR CYCLE 0                                 SETU0015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        SETU0020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXSETU0030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,SETU0040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  SETU0050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    SETU0060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        SETU0070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    SETU0080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   SETU0090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      SETU0100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  SETU0110
     1JPLHAF,JMLHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   SETU0120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      SETU0130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   SETU0140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),SETU0150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),SETU0160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         SETU0170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)SETU0180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   SETU0190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   SETU0200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),SETU0210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   SETU0220
      N=1                                                               SETU0230
      NMNHAF=N                                                          SETU0240
      NPL3HF=N                                                          SETU0250
      NPLUS1=1                                                          SETU0260
      NPLHAF=NPLUS1                                                     SETU0270
      NN=3                                                              SETU0280
      NCYCLE=0                                                          SETU0290
      T=0.                                                              SETU0300
      DTMIN(NN)=0.                                                      SETU0310
      TNEXT=OUTDT1                                                      SETU0320
      TPRINT=OUTDT1                                                     SETU0330
      TMAX=TMAX1                                                        SETU0340
      CALL GENSUB                                                       SETU0350
      NPLUS1=2                                                          SETU0360
      NPLHAF=NPLUS1                                                     SETU0370
      DTMIN(NN)=.0001                                                   SETU0380
      DTMIN(NPLHAF)=.0001                                               SETU0390
      TMINSQ(NPLHAF)=.00000001                                          SETU0400
       RETURN                                                           SETU0410
      END                                                               SETU0420
```

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      SUBROUTINE LFTOVR                                                      LFT00010
C   DETERMINES DELTA T AND PRINT CYCLE                                       LFT00015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL             LFT00020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXLFT00030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,LFT00040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  LFT00050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    LFT00060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,         LFT00070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    LFT00080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   LFT00090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP       LFT00100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   LFT00110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   LFT00120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,       LFT00130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PC,TO,AMOL,DUMVAR    LFT00140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),LFT00150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),LFT00160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         LFT00170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)LFT00180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   LFT00190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   LFT00200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),LFT00210
     7ZMASS(200),PC(30),TO(30),AMOL(30),DUMVAR(500,5)                     LFT00220
      DTLAST=DTMIN(NPLHAF)                                                 LFT00230
      M=INTERJ(31)                                                         LFT00240
      IF(SIGMAX.EQ.0.0)GO TO 240                                           LFT00250
      SIG1IN=1./SIGMAX                                                     LFT00260
      GO TO 244                                                            LFT00270
  240 SIGMIN=0.0                                                           LFT00280
  244 IF(SIGMIN-7.41*TMINSQ(NPLHAF)) 270,270,250                           LFT00290
  250 IF(DLAMAX-.079) 255,270,270                                          LFT00300
  255 IF(SIGMIN-11.11*TMINSQ(NPLHAF)) 265,260,260                          LFT00310
  260 IF(DLAMAX-.065) 270,270,265                                          LFT00320
  265 TMINSQ(NPL3HF)=TMINSQ(NPLHAF)                                        LFT00330
      GO TO 285                                                            LFT00340
  270 IF(DLAMAX-.01) 275,275,280                                           LFT00350
  275 TMINSQ(NPL3HF)=SIGMIN/2.25                                           LFT00360
      GO TO 285                                                            LFT00370
  280 TMINSQ(NPL3HF)=AMIN1(SIGMIN/9.00,.005184*TMINSQ(NPLHAF)/DLAMAX**2)LFT00380
  285 DTMIN(NPL3HF)=AMIN1(SQRT (TMINSQ(NPL3HF)),1.4*DTMIN(NPLHAF))         LFT00390
  290 DTMIN(NN)=(DTMIN(NPL3HF)+DTMIN(NPLHAF))/2.                           LFT00400
      NP=NPLUS1                                                            LFT00410
      NPLUS1=N                                                             LFT00420
      NPLHAF=NPLUS1                                                        LFT00430
      N=NP                                                                 LFT00440
      NMNHAF=N                                                             LFT00450
      NPL3HF=N                                                             LFT00460
      EINSUM=0.                                                            LFT00470
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      ESUM=0.                                                          LFT00480
      EKSUM=0.                                                         LFT00490
      USQ(1)=U(1,N)**2                                                 LFT00500
      DO 300 I=1,IMAX                                                  LFT00510
      EINT(I)=0.                                                       LFT00520
      EKIN(I)=0.                                                       LFT00530
      JMIN=INTERJ(I)                                                   LFT00540
      JMAX=INTERJ(I+1)-1                                               LFT00550
      DO 295 J=JMIN,JMAX                                               LFT00560
      JPLHAF=J                                                         LFT00570
      USQ(J+1)=U(J+1,N)**2                                             LFT00580
      X1(JPLHAF)  =(X(J,N)+X(J+1,N))/2.                                LFT00590
      EINT(I)=EINT(I)+E(JPLHAF,N)/HALFRO(I)*HALFM(JPLHAF)              LFT00600
  295 EKIN(I)=(USQ(J)+USQ(J+1))*HALFM(JPLHAF)    +EKIN(I)              LFT00610
      EKIN(I)=.5*EKIN(I)                                               LFT00620
      EINSUM=EINSUM+EINT(I)                                            LFT00630
      EKIN(6)=.5*EMPROJ*U(JLAST;NMNHAF)**2+EKIN(6)                     LFT00640
      EKSUM=   .5*EMPROJ*U(JLAST,NMNHAF)**2+EKSUM                      LFT00650
  300 EKSUM=EKSUM+EKIN(I)                                              LFT00660
      ESUM=EINSUM+EKSUM                                                LFT00670
      IF(NCHEKE) 301,305,301                                           LFT00680
  301 IF(ABS (ETOT-ESUM)-ETENTH) 305,305,302                           LFT00690
  302 EWRONG=1.                                                        LFT00700
      CALL OUTPUT                                                      LFT00710
  305 IF(JPROJ-400)306,306,307                                         LFT00720
  307 JPROJ=300                                                        LFT00730
      TPRINT=TMAX2                                                     LFT00740
      TNEXT=T+TPRINT                                                   LFT00750
      CALL OUTPUT                                                      LFT00760
      GO TO 121                                                        LFT00770
  306 IF(TNEXT-T) 315,315,121                                          LFT00780
  315 CALL OUTPUT                                                      LFT00790
  316 TNEXT=TNEXT+TPRINT                                               LFT00800
      IF(TMAX-TNEXT+.001)320,121,121                                   LFT00810
  320 TNEXT=TNEXT-TPRINT                                               LFT00820
      TPRINT=OUTDT2                                                    LFT00830
      TNEXT=TNEXT+TPRINT                                               LFT00840
      TMAX=5.*TMAX                                                     LFT00850
  121 IF(XSTOP-X(JLAST,NPLUS1)) 556,555,555                            LFT00860
  556 CALL OUTPUT                                                      LFT00870
  555 RETURN                                                           LFT00880
      END                                                              LFT00890
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      SUBROUTINE OUTPUT                                                 OUTP0010
C   PRINTS OUTPUT PARAMETERS                                            OUTP0015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        OUTP0020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXOUTP0030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,OUTP0040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH, OUTP0050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,   OUTP0060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        OUTP0070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,   OUTP0080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,  OUTP0090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP     OUTP0100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  OUTP0110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,  OUTP0120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,     OUTP0130
     3NPLHAF,MN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR  OUTP0140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),OUTP0150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),OUTP0160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),        OUTP0170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)OUTP0180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),  OUTP0190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  OUTP0200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),OUTP0210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   OUTP0220
      DIMENSION XP5(200), PP5(200),XP6(200),VP6(200)                    OUTP0230
      M=INTERJ(31)                                                      OUTP0240
      ILIMIT =IMAX                                                      OUTP0250
   49 WRITE(M,1)K,NUMBER,NDATE1,NDATE2,NDATE3                           OUTP0260
   51 WRITE(M,12)                                                       OUTP0270
   52 WRITE(M,6) NCYCLE,T,DTLAST,ESUM                                   OUTP0280
      IF(NCYCLE) 53,53,400                                              OUTP0290
   53 DO 57 JPLHAF=1,JLAST1                                             OUTP0300
   57 ZMASS(JPLHAF)=2.* HALFM(JPLHAF)                                   OUTP0310
   60 WRITE(M,2)                                                        OUTP0320
      WRITE(M,3)                                                        OUTP0330
      WRITE (M,5555)                                                    OUTP0340
      DO 604 L=1,JLAST1                                                 OUTP0350
      DO 602 IL=2,ILIMIT                                                OUTP0360
      IF(L-INTERJ(IL) ) 602,603,602                                     OUTP0370
  602 CONTINUE                                                          OUTP0380
      WRITE(M,4) L,X(L,N),U(L,NMNHAF),V(L,N),PPLUSQ(L),Q(L,NMNHAF),     OUTP0390
     1E(L,N),AREA(L,N),DTSQ(L),ZMASS(L)                                 OUTP0400
      GO TO 604                                                         OUTP0410
  603 WRITE(M,5556)                                                     OUTP0420
 5556 FORMAT(1H0)                                                       OUTP0430
      WRITE(M,4) L,X(L,N),U(L,NMNHAF),V(L,N),PPLUSQ(L),Q(L,NMNHAF),     OUTP0440
     1E(L,N),AREA(L,N),DTSQ(L),ZMASS(L)                                 OUTP0450
  604 CONTINUE                                                          OUTP0460
      WRITE(M,4) JLAST,X(JLAST,N),U(JLAST,NMNHAF)                       OUTP0470
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      GO TO 71                                                                  OUTP0480
400    NYDRA2 = HYDRD2                                                          OUTP0490
       IF((NYDRA2.EQ.0).OR.((NYDRA2-60).EQ.0).OR.((NYDRA2-30) .EQ.0))           OUTP0500
     1   GO TO 100                                                             OUTP0510
       IF((NYDRA2.GT.30).AND.(NYDRA2.LT.60))  GO TO 300                        OUTP0520
         IF(NYDRA2.GT.60)  GO TO 600                                           OUTP0530
         NZN =1                                                                OUTP0540
         MZM =  INTERJ(NYDRA2 +1) - 1                                          OUTP0550
         GO TO  200                                                            OUTP0560
 300     NYDRA2  =  NYDRA2 -30                                                 OUTP0570
         NZN   =   INTERJ(NYDRA2)                                              OUTP0580
         MZM   =   INTERJ(NYDRA2+1) -1                                         OUTP0590
       GO TO  200                                                              OUTP0600
 600   NYDRA2 = NYDRA2 -60                                                     OUTP0610
       NZN   = INTERJ(NYDRA2)                                                  OUTP0620
       MZM   =  JLAST1                                                         OUTP0630
 200    DO 70  JK = NZN,MZM                                                    OUTP0640
       JKM=JK-NZN  + 1                                                         OUTP0650
       XP6(JKM)=X1(JK)                                                         OUTP0660
       VP6(JKM)=U(JK,NMNHAF)/100.                                              OUTP0670
       XP5(JKM)=X1(JK)                                                         OUTP0680
  70   PP5(JKM)=PPLUSQ(JK)                                                     OUTP0690
 100    CONTINUE                                                               OUTP0740
       WRITE (M,7)                                                             OUTP0750
       WRITE(M,8)                                                              OUTP0760
       WRITE (M,5555)                                                          OUTP0770
       DO 704 L=1,JLAST1                                                       OUTP0780
       DO 702 IL=2,ILIMIT                                                      OUTP0790
       IF(L-INTERJ(IL)) 702,703,702                                            OUTP0800
 702   CONTINUE                                                                OUTP0810
       WRITE(M,4) L,X(L,N),U(L,NMNHAF),V(L,N),PPLUSQ(L),Q(L,NMNHAF),           OUTP0820
     1E(L,N),AREA(L,N),DTSQ(L),X1(L)                                           OUTP0830
       GO TO 704                                                               OUTP0840
 703   WRITE(M,5555)                                                           OUTP0850
5555   FORMAT(1H )                                                             OUTP0860
       WRITE(M,4) L,X(L,N),U(L,NMNHAF),V(L,N),PPLUSQ(L),Q(L,NMNHAF),           OUTP0870
     1E(L,N),AREA(L,N),DTSQ(L),X1(L)                                           OUTP0880
 704   CONTINUE                                                                OUTP0890
       WRITE(M,4) JLAST,X(JLAST,N),U(JLAST,NMNHAF)                             OUTP0900
  71   WRITE (M,9)                                                             OUTP0910
  75   WRITE(M,10) (I,NEQST(I),EKIN(I),EINT(I),I=1,IMAX)                       OUTP0920
       WRITE(M,6) NCYCLE,T,DTLAST,ESUM                                         OUTP0930
       WRITE(M,5)                                                              OUTP0940
    5  FORMAT(1H1)                                                             OUTP0950
       IF(EWRONG) 95,95,80                                                     OUTP0960
   80  WRITE(M,11)                                                             OUTP0970
   95  RETURN                                                                  OUTP0980
   40  FORMAT(1I5,1P7E13.5)                                                    OUTP0990
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    1 FORMAT(5X, I2,20H  H V MODEL LAUNCHER,4I3)                                    OUTP1000
    2 FORMAT(118HO   J     X(J,N)       U(J,N-1/2)    V(J+1/2,N)    P(J+1/2,NOUTP1010
     1) Q(J+1/2,N-1/2) E(J+1/2,N)  AREA(J,N) DTSQ(1/2,1/2)  DM(J+1/2))  OUTP1020
    3 FORMAT(114H          CM          CM/MILLISEC    CC/CCO          BARS  OUTP1030
     1       BARS      BARS-CC/CCO              MILLISECSQ   GRAMS)        OUTP1040
    4 FORMAT(I4,1P6E13.5,2E11.3,E13.5)                                      OUTP1050
    6 FORMAT(I5,1P3E15.5)                                                   OUTP1060
    7 FORMAT(119HO   J     X(J,N)       U(J,N-1/2)    V(J+1/2,N)    P(J+1/2,NOUTP1070
     1) Q(J+1/2,N-1/2) E(J+1/2,N) AREA(J,N)  DTSQ(1/2,1/2)  X(J+1/2,N))  OUTP1080
    8 FORMAT(114H          CM          CM/MILLISEC    CC/CCO          BARS  OUTP1090
     1       BARS      BARS-CC/CCO              MILLISECSQ     CM )        OUTP1100
    9 FORMAT(46HOREGION  MATERIAL      K-ENERGY        I-ENERGY)           OUTP1110
   10 FORMAT(I5,I8,          2E15.5)                                        OUTP1120
   11 FORMAT(53H1                                          ENERGY CHECK)   OUTP1130
   12 FORMAT(47HOCYCLE       T              DT           TOTAL E)          OUTP1140
      END                                                                   OUTP1150
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      SUBROUTINE CALCUL (EMLEAD)                                                CALC0010
C     CALCULATES INITIAL REGIONAL ENERGY, SPECIFIC VOLUME, AND DENSITY          CALC0015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL                CALC0020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXCALC0030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,CALC0040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  CALC0050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    CALC0060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,         CALC0070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    CALC0080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   CALC0090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      CALC0100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   CALC0110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   CALC0120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      CALC0130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   CALC0140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),CALC0150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),CALC0160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         CALC0170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)CALC0180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   CALC0190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   CALC0200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),CALC0210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    CALC0220
      M=INTERJ(31)                                                       CALC0230
      DO  50 I=1, IMAX                                                   CALC0240
        ROZERO(I)=AMOL(I)/22.4E3                                         CALC0250
      VZERO(I)=R*TO(I)/PO(I)/AMOL(I)*14.5/1.E6*ROZERO(I)                 CALC0260
   50   EZERO(I) = PO(I)*VZERO(I)/(GAMMA(I) -1.)/14.5                     CALC0270
      WRITE(M,21)                                                        CALC0280
   21 FORMAT(1H1)                                                        CALC0290
      DO 25 IK=1,IMAX                                                    CALC0300
      IF(PO(IK).NE.1.0) GO TO 23                                         CALC0310
      GAMMA(IK)=1.                                                       CALC0320
      EZERO(IK)=0.                                                       CALC0330
      VZERO(IK)=1.0                                                      CALC0340
       ROZERO(IK)= EMLEAD*453.7/(AREA2*(OUTBDY(2)-OUTBDY(1)))            CALC0350
   23 IF(PO(IK).NE.2.0)  GO TO 24                                        CALC0360
      GAMMA(IK)=1.                                                       CALC0370
      EZERO(IK)=0.                                                       CALC0380
      VZERO(IK)=1.0                                                      CALC0390
       ROZERO(IK)= EMPIST*453.7/(AREA2*(OUTBDY(3)-OUTBDY(2)))            CALC0400
   24 IF (PO(IK).NE.3.0) GO TO 25                                        CALC0410
      GAMMA(IK)=1.                                                       CALC0420
      EZERO(IK)=0.                                                       CALC0430
      VZERO(IK)=1.0                                                      CALC0440
      ROZERO(IK)=    EMPROJ/(AREA3*(OUTBDY(6)-OUTBDY(5)))                CALC0450
      EMPROJ=0.0                                                         CALC0460
   25 CONTINUE                                                           CALC0470
```

```
      RETURN                                                    CALC0590
      END                                                       CALC0600
```

```
      SUBROUTINE ZEOAB                                                  ZERO0010
C     ZEROS ALL VARIABLES BETWEEN RUNS                                  ZERO0015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        ZERO0020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXZERO0030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,ZERO0040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  ZERO0050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    ZERO0060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        ZERO0070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    ZERO0080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   ZERO0090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      ZERO0100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   ZERO0110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   ZERO0120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      ZERO0130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   ZERO0140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),ZERO0150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),ZERO0160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         ZERO0170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)ZERO0180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   ZERO0190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   ZERO0200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),ZERO0210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    ZERO0220
      CALL ZERO(AREA1,AREA2,AREA3,CSQMAX,DLAMAX,DUDT,DTLAST,DLAST1)      ZERO0230
      CALL ZERO(DJLAST,DNZONE,DMU,DPDE,DPDMU,EINSUM,ESUM,EKSUM)          ZERO0240
      CALL ZERO(ETOT,ETENTH,EWRONG,E1,HYDRD1,HYDRD2,HYDRD3,OUTDT1)       ZERO0250
      CALL ZERO(OUTDT2,PCON1,PCON2,P1,SHPR,SIGMAX,SIGMIN,TMAX1)          ZERO0260
      CALL ZERO(TMAX2,TVDT1,TVDT2,T,TMAX,TNEXT,TPRINT,TVNEXT)            ZERO0270
      CALL ZERO(TVFREQ,TBAR,TWALL,VOLUME,XGRID,XMIN,XMAX,EMPROJ)         ZERO0280
      CALL ZERO(XSTOP,AREA1,AREA2,AREA3,CSQMAX,T,T,T)                    ZERO0290
      CALL IERO(INDEX,IMAX,INU,I,INDEX,ILIMIT,JPROJ1,JPROJ2)             ZERO0300
      CALL IERO(JMIN,JMAX,J,JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1)            ZERO0310
      CALL IERO(JMAX1,K,L,NDATE1,NDATE2,NDATE3,NUMBER,NTV)               ZERO0320
      CALL IERO(NCHEKE,NCYCLE,N,NMNHAF,NPLUS1,NPLHAF,NN,NPL3HF)          ZERO0330
      CALL IERO(NP,IQUIT,JPROJ,JSTOP,K,K,K,K)                            ZERO0340
      CALL ZEROA(30,CQSQX4,CMAXR,CP,CV,DELX)                             ZERO0350
      CALL ZEROA(200,CSQ,DLAMDA,DTSQ,DQ1,DQ2)                            ZERO0360
      CALL ZEROA(3,DTMIN,DTMIN,DTMIN,DTMIN,DTMIN)                        ZERO0370
      CALL ZEROA(30,EZERO,EINT,EKIN,GAMMA,HALFRO)                        ZERO0380
      CALL ZEROA(30,NEQST,NZONES,OUTBDY,ROZERO,TOVRE1)                   ZERO0390
      CALL ZEROA(200,DS,FORCE,HALFM,HYDRAD,MACHSQ)                       ZERO0400
      CALL ZEROA(31,INTERJ,INTERJ,INTERJ,INTERJ,INTERJ)                  ZERO0410
      CALL ZEROA(30,OUTBDY,ROZERO,TOVRE1,TOVRE1,TOVRE1)                  ZERO0420
      CALL ZEROA(200,DS,FORCE,HALFM,HYDRAD,HYDRAD)                       ZERO0430
      DO 52 IA=1,200                                                     ZERO0440
   52 MACHSQ(IA)=0                                                       ZERO0450
      DO 54 IB=1,30                                                      ZERO0460
      NEQST(IB)=0                                                        ZERO0470
```

```
      NZONES(IB)=0                                                      ZERO0480
   54 INTERJ(IB)=0                                                      ZERO0490
      INTERJ(31)=0                                                      ZERO0500
      CALL ZEROA(200,PPLUSQ,SKIN,TSIGSQ,THETA,VISCOS)                   ZERO0510
      CALL ZEROA(2,TMINSQ,TMINSQ,TMINSQ,TMINSQ,TMINSQ)                  ZERO0520
      CALL ZEROA(30,VZERO,UZERO,UZERO,UZERO,UZERO)                      ZERO0530
      CALL ZEROA(201,USQ,USQ,USQ,USQ,USQ)                               ZERO0540
      CALL ZEROA(200,X1,ZMASS,X1,X1,X1)                                 ZERO0550
      CALL ZEROB(E,200,2)                                               ZERO0560
      CALL ZEROB(AREA,200,2)                                            ZERO0570
      CALL ZEROB(Q,200,2)                                               ZERO0580
      CALL ZEROB(U,201,2)                                               ZERO0590
      CALL ZEROB(V,200,2)                                               ZERO0600
      CALL ZEROB(P,200,2)                                               ZERO0610
      CALL ZEROB(X,201,2)                                               ZERO0620
      RETURN                                                            ZERO0630
      END                                                               ZERO0640
```

```
      SUBROUTINE IERO(I1,I2,I3,I4,I5,I6,I7,I8)                          ZERO0650
C     ZEROS INTEGERS                                                    ZERO0655
      I1=0                                                              ZERO0660
      I2=0                                                              ZERO0670
      I3=0                                                              ZERO0680
      I4=0                                                              ZERO0690
      I5=0                                                              ZERO0700
      I6=0                                                              ZERO0710
      I7=0                                                              ZERO0720
      I8=0                                                              ZERO0730
      RETURN                                                            ZERO0740
      END                                                               ZERO0750

      SUBROUTINE ZERO(Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8)                          ZERO0760
C     ZEROS NON-INTEGERS                                                ZERO0765
      Z1=0.                                                             ZERO0770
      Z2=0.                                                             ZERO0780
      Z3=0.                                                             ZERO0790
      Z4=0.                                                             ZERO0800
      Z5=0.                                                             ZERO0810
      Z6=0.                                                             ZERO0820
      Z7=0.                                                             ZERO0830
      Z8=0.                                                             ZERO0840
      RETURN                                                            ZERO0850
      END                                                               ZERO0860

      SUBROUTINE ZEROA(IZA,ZA1,ZA2,ZA3,ZA4,ZA5)                         ZERO0870
C  ZEROS VECTORS                                                        ZERO0875
      DIMENSION  ZA1(300),ZA2(300),ZA3(300),ZA4(300),ZA5(300)           ZERO0880
      DO 1  IZZ=1, IZA                                                  ZERO0890
      ZA1(IZZ)=0.                                                       ZERO0900
      ZA2(IZZ)=0.                                                       ZERO0910
      ZA3(IZZ)=0.                                                       ZERO0920
      ZA4(IZZ)=0.                                                       ZERO0930
      ZA5(IZZ)=0.                                                       ZERO0940
    1 CONTINUE                                                          ZERO0950
      RETURN                                                            ZERO0960
      END                                                               ZERO0970

      SUBROUTINE ZEROB(ZAB,IZA,JZB)                                     ZERO0980
C     ZEROS ARRAYS                                                      ZERO0985
      DIMENSION ZAB (300,10)                                            ZERO0990
      DO 2 IZZ=1,IZA                                                    ZERO1000
```

```
      DO 1  JZZ=1, JZB                                          ZERO1010
    1 ZAB(IZZ,JZZ)=0.                                           ZERO1020
    2 CONTINUE                                                  ZERO1030
      RETURN                                                    ZERO1040
      END                                                       ZERO1050
```

```
      SUBROUTINE STORIN  (ISTORM,STORM)                                 STIN0010
C     STORAGE ROUTINE                                                   STIN0015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        STIN0020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXSTIN0030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,STIN0040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH, STIN0050
     3EWORK,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    STIN0060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,       STIN0070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,  STIN0080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL, STIN0090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP     STIN0100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  STIN0110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,  STIN0120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,     STIN0130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR  STIN0140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),STIN0150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),STIN0160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),        STIN0170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)STIN0180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),  STIN0190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  STIN0200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),STIN0210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   STIN0220
      DIMENSION ISTORM(100), STORM(100)                                 STIN0230
      JPROJ=0                                                           STIN0240
      IDUM=0                                                            STIN0250
      PVWANT=0.                                                         STIN0260
      PVSLPE=0.                                                         STIN0270
       PRESCG = 0.                                                      STIN0280
       PVERR = 0.                                                       STIN0290
       XPV2 = 0.                                                        STIN0300
       XPV1 = 0.                                                        STIN0310
      ISTORM( 1) = IMAX                                                 STIN0320
      ISTORM( 2) = NDATE1                                               STIN0330
      ISTORM( 3) = NDATE2                                               STIN0340
      ISTORM( 4) = NDATE3                                               STIN0350
      ISTORM( 5) = NUMBER                                               STIN0360
      ISTORM( 6) = NCHEKE                                               STIN0370
      ISTORM( 7) = IMU                                                  STIN0380
      ISTORM( 8) = JPROJ                                                STIN0390
      ISTORM( 9) = IHEL                                                 STIN0400
      ISTORM(10) = IDUM                                                 STIN0410
      DO 1 IN=1,    IMAX                                                STIN0420
      IN10=IN+10                                                        STIN0430
      IN20=IN+20                                                        STIN0440
      IN30=IN+30                                                        STIN0450
      IN40=IN+40                                                        STIN0460
      IN50=IN+50                                                        STIN0470
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      IN60=IN+60                                                        STIN0480
      ISTORM(IN10)= NEQST(IN)                                           STIN0490
      ISTORM(IN20)= NZONES(IN)                                          STIN0500
      STORM(IN)= OUTBDY(IN)                                             STIN0510
      STORM(IN10)= GAMMA(IN)                                            STIN0520
      STORM(IN20)= CQSQX4(IN)                                           STIN0530
      STORM(IN30)= UZERO(IN)                                            STIN0540
      STORM(IN40)= PO (IN)                                              STIN0550
      STORM(IN50)= TO (IN)                                              STIN0560
      STORM(IN60)= AMOL(IN)                                             STIN0570
    1 CONTINUE                                                          STIN0580
       STORM(71)= AREA1                                                 STIN0590
       STORM(72)= AREA2                                                 STIN0600
       STORM(73)= AREA3                                                 STIN0610
       STORM(74)= PCON1                                                 STIN0620
       STORM(75)= PCON2                                                 STIN0630
       STORM(76)= SHPR                                                  STIN0640
       STORM(77)= EMPROJ                                                STIN0650
       STORM(78)= OUTDT1                                                STIN0660
       STORM(79)= TMAX1                                                 STIN0670
       STORM(80)= OUTDT2                                                STIN0680
       STORM(81)= TMAX2                                                 STIN0690
       STORM(82)= XSTOP                                                 STIN0700
       STORM(83)= PCON3                                                 STIN0710
       STORM(84)= SLOPE                                                 STIN0720
       STORM(85)= RADIUS                                                STIN0730
       STORM(86)= CALPGM                                                STIN0740
       STORM(87)= TBURND                                                STIN0750
       STORM(88)= GMSPDR                                                STIN0760
       STORM(89)= GASPRS                                                STIN0770
       STORM(90)= R                                                     STIN0780
       STORM(91)= EMPIST                                                STIN0790
      STORM(92)=PVWANT                                                  STIN0800
      STORM(93)=PVSLPE                                                  STIN0810
      STORM(94)=XPV1                                                    STIN0820
      STORM(95)=XPV2                                                    STIN0830
      STORM(96)=PVERR                                                   STIN0840
      STORM(97)= PRESCG                                                 STIN0850
      RETURN                                                            STIN0860
      END                                                               STIN0870
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      SUBROUTINE  STORE (ISTORM, STORM)                                 STRE0010
C     STORAGE ROUTINE                                                   STRE0015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        STRE0020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXSTRE0030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,STRE0040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  STRE0050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    STRE0060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        STRE0070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    STRE0080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   STRE0090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      STRE0100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  STRE0110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   STRE0120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      STRE0130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   STRE0140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),STRE0150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),STRE0160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         STRE0170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)STRE0180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   STRE0190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   STRE0200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),STRE0210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    STRE0220
      DIMENSION ISTORM(100), STORM(100)                                 STRE0230
      IMAX   = ISTORM(1)                                                STRE0240
      NDATE1= ISTORM(2)                                                 STRE0250
      NDATE2= ISTORM(3)                                                 STRE0260
      NDATE3= ISTORM(4)                                                 STRE0270
      NUMBER= ISTORM(5)                                                 STRE0280
      NCHEKE= ISTORM(6)                                                 STRE0290
      INU    = ISTORM(7)                                                STRE0300
      JPROJ  = ISTORM(8)                                                STRE0310
      IHEL   = ISTORM(9)                                                STRE0320
      IDUM   = ISTORM(10)                                               STRE0330
      DO 1 IN=1, IMAX                                                   STRE0340
      IN10=IN + 10                                                      STRE0350
      IN20=IN + 20                                                      STRE0360
      IN30=IN + 30                                                      STRE0370
      IN40=IN + 40                                                      STRE0380
      IN50=IN + 50                                                      STRE0390
      IN60=IN + 60                                                      STRE0400
      NEQST(IN)= ISTORM(IN10)                                           STRE0410
      NZONES(IN)=ISTORM(IN20)                                           STRE0420
      OUTBDY(IN)=STORM(IN)                                              STRE0430
      GAMMA (IN)=STORM(IN10)                                            STRE0440
      CQSQX4(IN)=STORM(IN20)                                            STRE0450
      UZERO (IN)=STORM(IN30)                                            STRE0460
      PO    (IN)=STORM(IN40)                                            STRE0470
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      TO     (IN)=STORM(IN50)                                          STRE0480
      AMOL   (IN)=STORM(IN60)                                          STRE0490
    1 CONTINUE                                                         STRE0500
      AREA1  =   STORM(71)                                             STRE0510
      AREA2  =   STORM(72)                                             STRE0520
      AREA3  =   STORM(73)                                             STRE0530
      PCON1  =   STORM(74)                                             STRE0540
      PCON2  =   STORM(75)                                             STRE0550
      SHPR   =   STORM(76)                                             STRE0560
      EMPROJ=    STORM(77)                                             STRE0570
      OUTDT1=    STORM(78)                                             STRE0580
      TMAX1  =   STORM(79)                                             STRE0590
      OUTDT2=    STORM(80)                                             STRE0600
      TMAX2  =   STORM(81)                                             STRE0610
      XSTOP  =   STORM(82)                                             STRE0620
      PCON3  =   STORM(83)                                             STRE0630
      SLOPE  =   STORM(84)                                             STRE0640
      RADIUS=    STORM(85)                                             STRE0650
      CALPGM=    STORM(86)                                             STRE0660
      TBUILND=   STORM(87)                                             STRE0670
      GMSPDR=    STORM(88)                                             STRE0680
      GASPRS=    STORM(89)                                             STRE0690
      R      =   STORM(90)                                             STRE0700
      EMPIST=    STORM(91)                                             STRE0710
      PVWANT=STORM(92)                                                 STRE0720
      PVSLPE=STORM(93)                                                 STRE0730
      XPV1=STORM(94)                                                   STRE0740
      XPV2=STORM(95)                                                   STRE0750
      PVERR=STORM(96)                                                  STRE0760
      PRESCG=STORM(97)                                                 STRE0770
      RETURN                                                           STRE0780
      END                                                              STRE0790
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```
      SUBROUTINE GENSUB                                                 GENS0010
C    SETS EQUATION PARAMETERS TO INITIAL CONDITIONS                     GENS0015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        GENS0020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXGENS0030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,GENS0040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  GENS0050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    GENS0060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        GENS0070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    GENS0080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   GENS0090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      GENS0100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  GENS0110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   GENS0120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      GENS0130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   GENS0140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),GENS0150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),GENS0160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         GENS0170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)GENS0180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   GENS0190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   GENS0200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),GENS0210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    GENS0220
      DO 35 I=1,IMAX                                                    GENS0230
   35 HALFRO(I)=ROZERO(I)/2.                                            GENS0240
      INTERJ(1)=1                                                       GENS0250
      DO 40 I=1,IMAX                                                    GENS0260
   40 INTERJ(I+1)=INTERJ(I)+NZONES(I)                                   GENS0270
      JLAST=INTERJ(IMAX+1)                                              GENS0280
      JLAST1=JLAST-1                                                    GENS0290
      DJLAST=JLAST                                                      GENS0300
      DLAST1=JLAST1                                                     GENS0310
      DNZONE=NZONES(1)                                                  GENS0320
      DELX(1)=OUTBDY(1)/DNZONE                                          GENS0330
      X(1,N)=0.                                                         GENS0340
      U(1,NMNHAF)=UZERO(1)                                              GENS0350
      DO 45 I=2,IMAX                                                    GENS0360
      DNZONE=NZONES(I)                                                  GENS0370
   45 DELX(I)=(OUTBDY(I)-OUTBDY(I-1))/DNZONE                            GENS0380
      DO 55 I=1,IMAX                                                    GENS0390
      JMIN=INTERJ(I)+1                                                  GENS0400
      JMAX=INTERJ(I+1)-1                                                GENS0410
      DO 50 J=JMIN,JMAX                                                 GENS0420
      JMNHAF=J-1                                                        GENS0430
      U(J,NMNHAF)=UZERO(I)                                              GENS0440
      V(JMNHAF,N)=VZERO(I)                                              GENS0450
      E(JMNHAF,N)=EZERO(I)                                              GENS0460
   50 X(J,N)=X(J-1,N)+DELX(I)                                           GENS0470
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```
      X(JMAX+1,N)=OUTBDY(I)                                              GENS0480
      U(JMAX+1,NMNHAF)=UZERO(I)                                          GENS0490
      E(JMAX,N)=EZERO(I)                                                 GENS0500
   55 V(JMAX,N)=VZERO(I)                                                 GENS0510
      DO 132 J=1,JLAST                                                   GENS0520
  132 CALL ARCCMP                                                        GENS0530
   65 DO 130 I=1,IMAX                                                    GENS0540
      JMIN=INTERJ(I)+1                                                   GENS0550
      JMAX=INTERJ(I+1)                                                   GENS0560
      DO 125 J=JMIN,JMAX                                                 GENS0570
      JMNHAF=J-1                                                         GENS0580
  120 CALL VCOMP                                                         GENS0590
      HALFM(JMNHAF)=HALFRO(I)/V(JMNHAF,N)*VOLUME                         GENS0600
  125 CONTINUE                                                           GENS0610
      HALFM(JLAST)=HALFM(JLAST)+EMPROJ                                   GENS0620
      INDEX=NEQST(I)                                                     GENS0630
      IF (INDEX.EQ.1) CALL EQST1                                         GENS0640
      IF (INDEX.EQ.2) CALL EQST2                                         GENS0641
      IF (INDEX.EQ.3) CALL EQST3                                         GENS0642
  130 CONTINUE                                                           GENS0650
      DO 135 JMNHAF=1,JLAST1                                             GENS0660
  135 PPLUSQ(JMNHAF)=P(JMNHAF,N)                                         GENS0670
  150 DK=1.                                                              GENS0680
      DK1=2.                                                             GENS0690
  155 EINSUM=0.                                                          GENS0700
      EKSUM=0.                                                           GENS0710
      ETOT=0.                                                            GENS0720
      USQ(1)=U(1,N)**2                                                   GENS0730
      DO 165 I=1,IMAX                                                    GENS0740
      EINT(I)=0.                                                         GENS0750
      EKIN(I)=0.                                                         GENS0760
      JMIN=INTERJ(I)                                                     GENS0770
      JMAX=INTERJ(I+1)-1                                                 GENS0780
      DO 160 J=JMIN,JMAX                                                 GENS0790
      JPLHAF=J                                                           GENS0800
      USQ(J+1)=U(J+1,N)**2                                               GENS0810
      EINT(I)=EINT(I)+E(JPLHAF,N)/HALFRO(I)*HALFM(JPLHAF)*DK             GENS0820
  160 EKIN(I)=(USQ(J)+USQ(J+1))*HALFM(JPLHAF)*DK+EKIN(I)                 GENS0830
      EKIN(I)=.5*EKIN(I)                                                 GENS0840
      EINSUM=EINSUM+EINT(I)                                              GENS0850
  165 EKSUM=EKSUM+EKIN(I)                                                GENS0860
      ETOT=EINSUM+EKSUM                                                  GENS0870
      ESUM=ETOT                                                          GENS0880
      ETENTH=.1*ETOT                                                     GENS0890
  175 XGRID=.125*(X(JMAX,N)-X(1,N))                                      GENS0900
      XMIN=X(1,N)-XGRID                                                  GENS0910
      XMAX=X(JMAX,N)+XGRID                                               GENS0920
  180 CALL OUTPUT                                                        GENS0930
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      RETURN                                                    GENS0940
      END                                                       GENS0950
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      SUBROUTINE DYNMEQ                                                 DYNM0010
C   CALCULATES MASS POINT VELOCITY AND ZONE SPECIFIC VOLUME AND         DYNM0015
C   BOUNDARIES                                                          DYNM0016
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        DYNM0020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXDYNM0030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,DYNM0040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  DYNM0050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    DYNM0060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        DYNM0070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,   DYNM0080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,  DYNM0090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP     DYNM0100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  DYNM0110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,  DYNM0120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      DYNM0130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR  DYNM0140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),DYNM0150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),DYNM0160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),        DYNM0170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)DYNM0180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),  DYNM0190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  DYNM0200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),DYNM0210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   DYNM0220
C 120 I=1                                                               DYNM0230
  120 CONTINUE                                                          DYNM0240
  125 DLAMAX=0.                                                         DYNM0250
      SIGMAX=0.                                                         DYNM0260
      T=T+DTMIN(NPLHAF)                                                 DYNM0270
      NCYCLE=NCYCLE+1                                                   DYNM0280
  150 DO 245 I=1,IMAX                                                   DYNM0290
      NZN=NZONES(I+1)                                                   DYNM0300
      CMAXR(I)=0.                                                       DYNM0310
      CSQMAX=0.                                                         DYNM0320
      JMIN=INTERJ(I)+1                                                  DYNM0330
      JMAX=INTERJ(I+1)                                                  DYNM0340
      DO 230 J=JMIN,JMAX                                                DYNM0350
      JPLHAF=J                                                          DYNM0360
      JMNHAF=J-1                                                        DYNM0370
  361 IF(JLAST-J) 155,155,1700                                          DYNM0380
  155 DUDT=PPLUSQ(JMNHAF)*AREA(JLAST,N)/HALFM(JMNHAF)                   DYNM0390
      IF(JPROJ.EQ.300.AND.E(JMNHAF,N) .NE.0.0)  GO TO 195               DYNM0400
      GO TO 901                                                         DYNM0410
 1700 IF(JPROJ.EQ.300) GO TO 1755                                       DYNM0420
      IF(J.EQ.INTERJ(6)) GO TO 901                                      DYNM0430
      IF(J.GT.INTERJ(6)) GO TO 902                                      DYNM0440
      GO TO 1755                                                        DYNM0450
  901 IF(PPLUSQ(JMNHAF)-SHPR) 902,903,903                               DYNM0460
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  902 U(J,NPLHAF)=0.0                                                                DYNM0470
      GO TO 196                                                                      DYNM0480
  903 JPROJ=500                                                                      DYNM0490
      DTSQ(200)=T                                                                    DYNM0500
 1755 IF(J.EQ.JMAX.AND.NZN.EQ.1) GO TO 876                                           DYNM0510
      IF(J.EQ.JMAX.AND.NZN.GT.1) GO TO 800                                           DYNM0520
      DUDT=(PPLUSQ(JMNHAF)-PPLUSQ(JPLHAF))*AREA(J,N)/(HALFM(JMNHAF)+                 DYNM0530
     1HALFM(JPLHAF))                                                                 DYNM0540
      GO TO 195                                                                      DYNM0550
  800 IF(J.EQ.INTERJ(6)) GO TO 863                                                   DYNM0560
      DUDT =-(1.5*(PPLUSQ(JPLHAF)-PPLUSQ(JMNHAF))-(PPLUSQ(JPLHAF+1)-                 DYNM0570
     1 PPLUSQ(JMNHAF-1))/6.)*AREA(J,N)/(HALFM(JMNHAF)+HALFM(JPLHAF))                 DYNM0580
      GO TO 195                                                                      DYNM0590
  863 DUDT =-(1.5*(PPLUSQ(JPLHAF)-PPLUSQ(JMNHAF))-(PPLUSQ(JPLHAF+1)-                 DYNM0600
     1   (PPLUSQ(JMNHAF)/3.+2.*PPLUSQ(JMNHAF-1)/3.)                                  DYNM0610
     1                    )/6.)*AREA(J,N)/(HALFM(JMNHAF)+HALFM(JPLHAF))             DYNM0620
      IF(T.GE.(DTSQ(200)+DTSQ(199))) GO TO 194                                       DYNM0630
      DUDT=DUDT*(T-DTSQ(200))/DTSQ(199)                                              DYNM0640
  194 CONTINUE                                                                       DYNM0650
      GO TO 195                                                                      DYNM0660
  876 A=2.*HALFM(JMNHAF)                                                             DYNM0670
      B=HALFM(JMNHAF)+HALFM(JPLHAF)                                                  DYNM0680
      DUDT=((2.*A**2*PPLUSQ(JPLHAF))                                                 DYNM0690
     1      -(2.*A-B)*(A+B)*PPLUSQ(JMNHAF)                                           DYNM0700
     2      +(A-B)*B*PPLUSQ(JMNHAF-1)) /(A*(A+B)*B)*(-1.)*AREA(J,N)                  DYNM0710
  195 U(J,NPLHAF)=U(J,NMNHAF)+DTMIN(NN)*DUDT                                         DYNM0720
  196 X(J,NPLUS1)=X(J,N)+DTMIN(NPLHAF)*U(J,NPLHAF)                                   DYNM0730
      CALL ARCOMP                                                                    DYNM0740
      CALL VCOMP                                                                     DYNM0750
      V(JMNHAF,NPLUS1)=HALFRO(I)/HALFM(JMNHAF)*VOLUME                                DYNM0760
  200 IF(U(J,NPLHAF)-U(J-1,NPLHAF)) 205,225,225                                      DYNM0770
  205 Q(JMNHAF,NPLHAF)=CQSQX4(I)*HALFRO(I)*(U(J,NPLHAF)-U(J-1,NPLHAF))               DYNM0780
     1**2/(V(JMNHAF,NPLUS1)+V(JMNHAF,N))                                             DYNM0790
      GO TO 230                                                                      DYNM0800
  225 Q(JMNHAF,NPLHAF)=0.                                                            DYNM0810
  230 CONTINUE                                                                       DYNM0820
      INDEX=NEQST(I)                                                                 DYNM0830
      IF (INDEX.EQ.1) CALL EQST1                                                     DYNM0840
      IF (INDEX.EQ.2) CALL EQST2                                                     DYNM0841
      IF (INDEX.EQ.3) CALL EQST3                                                     DYNM0842
   53 DO 240 J=JMIN,JMAX                                                             DYNM0850
      JMNHAF=J-1                                                                     DYNM0860
      IF(JPROJ.LT.300.AND.J.GT.INTERJ(6)) GO TO 24                                   DYNM0870
      TSIGSQ(JMNHAF)=CSQ(JMNHAF)/(X(J,NPLUS1)-X(J-1,NPLUS1))**2                      DYNM0880
   24   CONTINUE                                                                     DYNM0890
      PPLUSQ(JMNHAF)=P(JMNHAF,NPLUS1)+Q(JMNHAF,NPLHAF)                               DYNM0900
      DLAMDA(JMNHAF)=CQSQX4(I)/2.*(V(JMNHAF,N      )-V(JMNHAF,NPLUS1))/              DYNM0910
     1(V(JMNHAF,N)+V(JMNHAF,NPLUS1))                                                 DYNM0920
```

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      DLAMAX= MAX1(DLAMDA(JMNHAF),DLAMAX)                                DYNM0940
      SIGMAX= MAX1(TSIGSQ(JMNHAF),SIGMAX)                                DYNM0950
      CSQMAX= MAX1(CSQMAX,CSQ(JMNHAF))                                   DYNM0960
      IF ( TSIGSQ(JMNHAF) .NE. 0.0 ) GO TO 240                           DYNM0970
      DTSQ(JMNHAF) =0.0                                                  DYNM0980
      GO TO 245                                                          DYNM0990
  240 DTSQ(JMNHAF)=.1111111/TSIGSQ(JMNHAF)                               DYNM1000
  245 CMAXR(I)=SQRT (CSQMAX)                                             DYNM1010
  340 CONTINUE                                                           DYNM1020
  246 RETURN                                                             DYNM1030
      END                                                                DYNM1040
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      SUBROUTINE ARCOMP                                                 ARC00010
C     DETERMINES ZONE CROSS SECTIONAL AREA                              ARC00015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        ARC00020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXARC00030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,ARC00040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  ARC00050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    ARC00060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        ARC00070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    ARC00080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   ARC00090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      ARC00100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   ARC00110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   ARC00120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      ARC00130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   ARC00140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),ARC00150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),ARC00160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         ARC00170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)ARC00180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   ARC00190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   ARC00200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),ARC00210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    ARC00220
   2  IF(X(J,NPLUS1)-PCON3) 5,4,4                                       ARC00230
   4  AREA(J,NPLUS1)=AREA3                                              ARC00240
      GO TO 10                                                          ARC00250
   5  IF(X(J,NPLUS1)-PCON2) 7,6,6                                       ARC00260
   6  AREA(J,NPLUS1)=AREA2                                              ARC00270
      GO TO 10                                                          ARC00280
   7  IF(X(J,NPLUS1)-PCON1) 9,8,8                                       ARC00290
   8  AREA(J,NPLUS1)=AREA2                                              ARC00300
      GO TO 10                                                          ARC00310
   9  AREA(J,NPLUS1)=AREA1                                              ARC00320
  10  RETURN                                                            ARC00330
      END                                                               ARC00340
```

```
      SUBROUTINE VCOMP                                                  VCOM0010
C     DETERMINES ZONE VOLUME                                            VCOM0015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        VCOM0020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXVCOM0030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,VCOM0040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  VCOM0050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    VCOM0060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        VCOM0070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    VCOM0080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   VCOM0090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      VCOM0100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   VCOM0110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   VCOM0120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      VCOM0130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   VCOM0140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),VCOM0150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),VCOM0160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         VCOM0170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)VCOM0180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   VCOM0190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   VCOM0200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),VCOM0210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   VCOM0220
      XPV1=0.                                                           VCOM0230
      XPV2=0.                                                           VCOM0240
      PVERR=0.                                                          VCOM0250
      PRESCG=0.                                                         VCOM0260
    2 IF(X(J,NPLUS1)-PCON1) 3,3,4                                       VCOM0270
    3 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA1                          VCOM0280
      GO TO 17                                                          VCOM0290
    4 IF(X(J,NPLUS1)-PCON2) 5,5,8                                       VCOM0300
    5 IF(X(J-1,NPLUS1)-PCON1) 6,7,7                                     VCOM0310
    6 VOLUME=(X(J,NPLUS1)-PCON1)*AREA2+(PCON1-X(J-1,NPLUS1))*AREA1      VCOM0320
      GO TO 17                                                          VCOM0330
    7 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA2                          VCOM0340
      GO TO 17                                                          VCOM0350
    8 IF(X(J,NPLUS1)-PCON3) 9,9,12                                      VCOM0360
    9 IF(X(J-1,NPLUS1)-PCON2) 10,11,11                                  VCOM0370
   10 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA2                          VCOM0380
      GO TO 17                                                          VCOM0400
   11 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA2                          VCOM0410
      GO TO 17                                                          VCOM0430
   12 IF(X(J-1,NPLUS1)-PCON3) 14,13,13                                  VCOM0440
   13 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA3                          VCOM0450
      GO TO 17                                                          VCOM0460
   14 IF(X(J-1,NPLUS1)-PCON2) 16,15,15                                  VCOM0470
   15 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA3                          VCOM0480
      GO TO 17                                                          VCOM0500
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```
   16 VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA3                    VCOM0530
   17 RETURN                                                      VCOM0540
      END
```

```
      SUBROUTINE EQST1                                                  EQS10010
C  CALCULATES PRESSURE AND ENERGY FOR IDEAL GAS ZONES                   EQS10015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        EQS10020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXEQS10030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,EQS10040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  EQS10050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    EQS10060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        EQS10070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,   EQS10080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,  EQS10090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP     EQS10100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  EQS10110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,  EQS10120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      EQS10130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,S,EMPIST,PO,TO,AMOL,DUMVAR  EQS10140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),EQS10150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),EQS10160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),        EQS10170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)EQS10180
     4.NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),  EQS10190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),  EQS10200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),EQS10210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                   EQS10220
      JMIN1=JMIN-1                                                      EQS10230
      JMAX1=JMAX-1                                                      EQS10240
      DO 10 JMNHAF=JMIN1,JMAX1                                          EQS10250
      E1=E(JMNHAF,N)-(P(JMNHAF,N)+Q(JMNHAF,NPLHAF))*(V(JMNHAF,NPLUS1)-  EQS10260
     1V(JMNHAF,N))                                                      EQS10270
      P1=E1*(GAMMA(I)-1.0)/ V(JMNHAF,NPLUS1)                            EQS10280
      E(JMNHAF,NPLUS1)=E1-.5*(P1-P(JMNHAF,N))*(V(JMNHAF,NPLUS1)-        EQS10290
     1V(JMNHAF,N))                                                      EQS10300
      P(JMNHAF,NPLUS1)=E(JMNHAF,NPLUS1)*(GAMMA(I)-1.0)/ V(JMNHAF,NPLUS1)EQS10310
10    CSQ(JMNHAF)=GAMMA(I)*(GAMMA(I)-1.0)*E(JMNHAF,NPLUS1)/ROZERO(I)    EQS10320
      RETURN                                                            EQS10330
      END                                                               EQS10340
```

```
      SUBROUTINE EQST2                                                  EQS20010
C  CALCULATES PRESSURE AND ENERGY FOR NON-IDEAL GAS ZONES               EQS20015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        EQS20020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXEQS20030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,EQS20040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  EQS20050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    EQS20060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        EQS20070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    EQS20080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   EQS20090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      EQS20100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,   EQS20110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   EQS20120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      EQS20130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   EQS20140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),EQS20150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),EQS20160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         EQS20170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)EQS20180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   EQS20190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   EQS20200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),EQS20210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    EQS20220
      IF (NCYCLE.EQ.1) T=0.0                                            EQS20225
      IF (T.GT..0000001) GO TO 3                                        EQS20226
C     IF(INTERJ(30))3,1,3                                               EQS20240
    1 NCHEKE=0                                                          EQS20250
      IBURND=0                                                          EQS20260
      TOLD=0.                                                           EQS20270
      INTERJ(30)=2                                                      EQS20280
      ZMASS(200)=2.                                                     EQS20290
      GASPRS=GASPRS/14.5                                                EQS20300
      PVOL=GMSPDR/1000.                                                 EQS20310
      GVOL=PCON1*AREA1*.001-PVOL                                        EQS20320
      GMOLES=GASPRS*GVOL/24.61                                          EQS20330
      PMOLES=GMSPDR/125.                                                EQS20340
      PRESUR=(GMOLES+PMOLES)*24.61/(GVOL+PVOL)*1.0138                   EQS20350
      IF(IHEL)40,40,35                                                  EQS20360
   35 GAMMA(I)=(GMOLES*1.667+PMOLES*1.23)/(GMOLES+PMOLES)               EQS20370
      WGTMOL=(GMOLES*4.0026+PMOLES*125.)/(GMOLES+PMOLES)                EQS20380
      GO TO 50                                                          EQS20390
   40 GAMMA(I)=(GMOLES*1.4+PMOLES*1.23)/(GMOLES+PMOLES)                 EQS20400
      WGTMOL=(GMOLES*2.+PMOLES*125.)/(GMOLES+PMOLES)                    EQS20410
   50 SPCVOL=83.17*300.0/(PRESUR*WGTMOL)                                EQS20420
      ROZERO(I)=WGTMOL/22400.                                           EQS20430
      VZERO(I)=SPCVOL*ROZERO(I)                                         EQS20440
      EZERO(I)=PRESUR*VZERO(I)/(GAMMA(I)-1.)                            EQS20450
      JMIN1=JMIN-1                                                      EQS20460
```

```
      JMAX1=JMAX-1                                                                  EQS20470
      DO 20 J=JMIN1,JMAX1                                                           EQS20480
      E(J,N)=EZERO(I)                                                               EQS20490
   20 V(J,N)=VZERO(I)                                                               EQS20500
      EPEAK=CALPGM*41.84*ROZERO(I)*PMOLES*125./(PMOLES*125.+GMOLES*2.0)             EQS20510
      HALFRO(I)=ROZERO(I)/2.                                                        EQS20520
      DO 30 J=JMIN,JMAX                                                             EQS20530
      VOLUME=(X(J,N)-X(J-1,N))*AREA1                                                EQS20540
   30 HALFM(J-1)=HALFRO(I)/V(J-1,N)*VOLUME                                          EQS20550
    3 JMIN1=JMIN-1                                                                  EQS20560
      JMAX1=JMAX-1                                                                  EQS20570
      IF(IBURND)4,4,7                                                               EQS20580
    4 IF ( TBURND .EQ. 0.0 ) GO TO 6                                                EQS20590
C     STATEMENT IF ( TBURND .EQ. 0.0 ) GO TO 6 WAS INSERTED DURING CON-             EQS20600
C     VERSION TO THE G.E. 635                                                       EQS20610
      IF(TBURND-T)6,5,5                                                             EQS20620
    5 DELE=EPEAK*(T-TOLD)/TBURND                                                    EQS20630
      TOLD=T                                                                        EQS20640
      GO TO 7                                                                       EQS20650
    6 DELE=0.                                                                       EQS20660
      IBURND=1                                                                      EQS20670
    7 DO 10 JMNHAF=JMIN1,JMAX1                                                      EQS20680
      E1=E(JMNHAF,N)-(P(JMNHAF,N)+Q(JMNHAF,NPLHAF))* (V(JMNHAF,NPLUS1)-             EQS20690
     1V(JMNHAF,N))+DELE                                                           EQS20700
      P1=(GAMMA(I)-1.)*E1/V(JMNHAF,NPLUS1)                                          EQS20710
      E(JMNHAF,NPLUS1)=E1-.5*(P1-P(JMNHAF,N))*(V(JMNHAF,NPLUS1)-                    EQS20720
     1V(JMNHAF,N))                                                                EQS20730
      P(JMNHAF,NPLUS1)=(GAMMA(I)-1.)*E(JMNHAF,NPLUS1)/V(JMNHAF,NPLUS1)              EQS20740
      CSQ(JMNHAF)=GAMMA(I)*(GAMMA(I)-1.)*E(JMNHAF,NPLUS1)/ROZERO(I)                 EQS20750
      IF(NCYCLE.NE.0) GO TO 10                                                      EQS20751
   10 CONTINUE                                                                      EQS20752
      RETURN                                                                        EQS20760
      END                                                                           EQS20770
```

```
      SUBROUTINE EQST3                                                  EQS30010
C  CALCULATES PRESSURE AND ENERGY FOR SOLID ZONES                       EQS30015
      COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSPDR,GASPRS,IHEL        EQS30020
      COMMON AREA1,AREA2,AREA3,AREA,CQSQX4,CMAXR,CSQ,CSQMAX,CP,CV,DLAMAXEQS30030
     1,DTMIN,DUDT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DNZONE,DELX,DMU,DPDE,EQS30040
     2DPDMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EINT,EKIN,E,ETOT,ETENTH,  EQS30050
     3EWRONG,E1,FORCE,GAMMA,HALFM,HALFRO,HYDRD1,HYDRD2,HYDRD3,HYDRAD,    EQS30060
     4OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPLUSQ,P,P1,Q,ROZERO,SHPR,        EQS30070
     5SIGMAX,SIGMIN,SKIN,TMAX1,TMAX2,TVDT1,TVDT2,T,TMAX,TSIGSQ,TNEXT,    EQS30080
     6TPRINT,TVNEXT,TMINSQ,TVFREQ,UZERO,U,USQ,TBAR,TOVRE1,THETA,TWALL,   EQS30090
     7VZERO,V,VOLUME,VISCOS,X,X1,XGRID,XMIN,XMAX,ZMASS,EMPROJ,XSTOP      EQS30100
      COMMON IMAX,INU,I,INTERJ,INDEX,ILIMIT,JPROJ1,JPROJ2,JMIN,JMAX,J,  EQS30110
     1JPLHAF,JMNHAF,JLAST,JLAST1,JMIN1,JMAX1,K,L,MACHSQ,NDATE1,NDATE2,   EQS30120
     2NDATE3,NUMBER,NTV,NCHEKE,NEQST,NZONES,NCYCLE,N,NMNHAF,NPLUS1,      EQS30130
     3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR   EQS30140
      DIMENSION AREA(200,2),CQSQX4(30),CMAXR(30),CSQ(200),CP(30),CV(30),EQS30150
     1DTMIN(3),DLAMDA(200),DTSQ(200),DELX(30),DQ1(200),DQ2(200),DS(200),EQS30160
     2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),         EQS30170
     3HALFM(200),HALFRO(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30)EQS30180
     4,NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),   EQS30190
     5SKIN(200),TSIGSQ(200),TMINSQ(2),TOVRE1(30),THETA(200),UZERO(30),   EQS30200
     6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),EQS30210
     7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(500,5)                    EQS30220
      JMIN1=JMIN-1                                                      EQS30230
      JMAX1=JMAX-1                                                      EQS30240
      DO 10 JMNHAF=JMIN1,JMAX1                                          EQS30250
      DMU=1./V(JMNHAF,NPLUS1)-1.                                        EQS30260
      E1=E(JMNHAF,N)-(P(JMNHAF,N)+Q(JMNHAF,NPLHAF))*(V(JMNHAF,NPLUS1)-  EQS30270
     1V(JMNHAF,N))                                                      EQS30280
      DPDMU=21297.0*(DMU+1.0)**6-3041.4                                 EQS30290
      P(JMNHAF,NPLUS1)=3042.4*(DMU+1.0)**7-3041.4                       EQS30300
      IF(P(JMNHAF,NPLUS1)+3000.) 9,11,11                                EQS30310
    9 P(JMNHAF,NPLUS1)=-3000.                                           EQS30320
   11 E(JMNHAF,NPLUS1)=E1-.5*(P(JMNHAF,NPLUS1)-P(JMNHAF,N))*(V(JMNHAF,  EQS30330
     1NPLUS1)-V(JMNHAF,N))                                              EQS30340
   10 CSQ(JMNHAF)=DPDMU/ROZERO(I)                                       EQS30350
      RETURN                                                            EQS30360
      END                                                               EQS30370
```

CARD 1 (4I3,F10.0)

IDATA = 0, STANDARD 18 CARD INPUT
= 1, NAMELIST INPUT OF ALL VARIABLES ON CARDS

IPRNTZ = 0, STANDARD RUN
= 1, PRINT OUT INITIAL DATA ONLY

INTRNSF = 0, USE DISK SCRATCH FILE AND PRINTOUT ONLY LAST PISTON ITERATION
= 1, PRINT OUT ALL PISTON ITERATIONS (HYPERVELOCITY MODEL ONLY)

IPUNCH = 0, NO PUNCHED OUTPUT
= 1, PUNCHED OUTPUT OF MODEL BASE PRESSURE VS TIME

DTSQ(199) FINITE BREAK VALVE OPENING TIME

CARD 2 (20I3)

IMAX = NUMBER OF REGIONS (UP TO SIX)

NDATE1 = MONTH

NDATE2 = DAY

NDATE3 = YEAR

NUMBER = RUN IDENTIFICATION NUMBER

NCHEKE = 0, NO ENERGY CHECK
= 1, ENERGY MONITORED AND PROBLEM STOPPED IF THE TOTAL ENERGY CHANGES BY MORE THAN 10%

INU = 0, ALL ZONES HAVE ZERO INITIAL VELOCITY
= 1, ALLOWS INITIAL VELOCITY FOR EACH ZONE TO BE READ

JPROJ = MASS POINT NUMBER OF PROJECTILE

CARD 3 (20I3)

NEQST(I) = NUMBER OR INDEX OF EQUATION OF STATE USED IN REGION I

CARD 4 (20I3)

NZONES(I) = NUMBER OF ZONES IN REGION I

CARD 5 (7F10.0)

OUTBDY(I) = DISTANCE IN CM TO OUTER INTERFACE OF REGION I

CARD 6 (7F10.0)

GAMMA(I) = RATIO OF SPECIFIC HEATS FOR REGION I

CARD 7 (7F10.0)

CQSQX4(I) = CONSTANT USED IN ARTIFICIAL VISCOSITY COMPUTATION (GOOD VALUES ARE 4.0 FOR GAS REGION, 9.0 FOR SOLID REGION)

CARD 8 (7F10.0)

AREA1 = AREA IN SQ CM OF FIRST CONSTANT AREA SECTION (PROGRAM ALLOWS UP TO THREE DIFFERENT CONSTANT AREA SECTIONS AND ONE TAPERED SECTION BETWEEN THE SECOND AND THIRD CONSTANT AREA SECTIONS)

AREA2 = AREA IN SQ CM OF SECOND CONSTANT AREA SECTION

AREA3 = AREA IN SQ CM OF THIRD CONSTANT AREA SECTION

PCON1 = POSITION IN CM WHERE FIRST AREA CHANGE OCCURS

PCON2 = POSITION IN CM WHERE SECOND AREA CHANGE OCCURS

SHPR = PROJECTILE RELEASE PRESSURE IN BARS

EMPROJ = MASS OF PROJECTILE IN GRAMS

OUTDT1 = DELTA T FOR PRINTING UP TO TIME TMAX1

TMAX1 = MILLISECS

OUTDT2 = DELTA T FOR PRINTING UP TO TIME TMAX2

TMAX2 = MILLISECS

XSTOP = POSITION IN CM THAT WHEN THE INTERFACE JSTOP REACHES IT, THE PROBLEM IS TERMINATED

CARD 9 (7F10.0) REQUIRED ONLY IF INU = 1

UZERO(I) = INITIAL VELOCITY FOR EACH ZONE

CARD 10 (7F10.0)

PCON = POSITION IN CM WHERE THIRD AREA CHANGE OCCURS

SLOPE = SLOPE OF CONSTANT TAPERED SECTION

RADIUS = RADIUS IN CM OF THE CONSTANT AREA SECTION TO THE RIGHT OF THE TAPERED SECTION

CARD 11 (4F10.0,I4)

CALPGM = CALORIES PER GRAM OF POWDER

TBURND = TIME TO BURN POWDER

GMSPDR = GRAMS OF POWDER

GASPRS = INITIAL GAS PRESSURE IN POWDER REGION

IHEL= 0 (NOT APPLICABLE TO GUN PROJECT)

CARD 12 (7F10.0)

IPOX = 0 ALL PLOTS, ALL PRESSURE POINTS (PLOT ROUTINE MUST BE INCLUDED)
= 1 ALL PLOTS, NO PRESSURE POINTS
= 5 NO PLOTS, NO PRESSURE POINTS
= 6 ONLY PRESSURE POINTS

NPOX = NUMBER OF PRESSURE POINTS (UP TO FIVE)

XPO(I) = X POSITION IN CM OF PRESSURE POINT I

CARD 13 (7F10.0) HYPERVELOCITY MODEL LAUNCHER PARAMETERS, (NOT APPLICABLE TO GUN PROJECT)

XPV1 = X POSITION IN CM OF FIRST MEASUREMENT POINT OF PISTON VELOCITY

XPV2 = X POSITION IN CM OF SECOND MEASUREMENT POINT OF PISTON VELOCITY

PVERR = PISTON VELOCITY ERROR IN FT PER SEC

PVWANT = DESIRED PISTON VELOCITY IN FT PER SEC

CARD 14 (E10.0,3F10.0)

R = .8317E 08 GAS CONSTANT

EMPIST = MASS OF FIRST PISTON SECTION (HYPERVELOCITY MODEL LAUNCHER ONLY)

FRAC = 1.0

EMLEAD = MASS OF SECOND PISTION SECTION (HYPERVELOCITY MODEL LAUNCHER)

CARD 15 (7F10.0)

PO(I) = INITIAL PRESSURE IN PSI IN REGION I

CARD 16 (7F10.0)

TO(I) = INITIAL TEMPERATURE IN DEGREES KELVIN IN REGION I

CARD 17 (7F10.0)

AMOL(I) = MOLECULAR WEIGHT OF MATERIAL IN REGION I

CARD 18 (I3)

ILASTK = 0, STOP
= 1, CONTINUE FOR NEW RUN

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